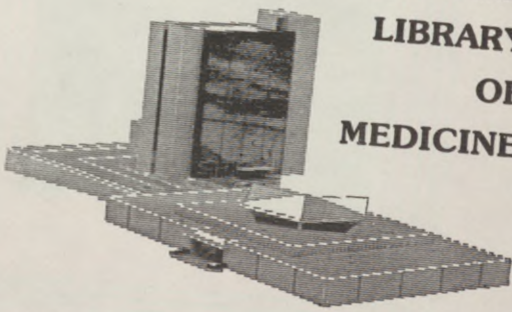
THE TRANSPLANTATION OF TISSUES

HAROLD NEUHOF



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Homograft of Skin

From tattooed areas of a man in Blood Group IV (universal donor) to a skin defect following radical mastectomy for carcinoma in a patient in Group I (universal recipient). Six months after skin grafting. The discharge from the necrotic rib persists and the graft directly adjacent is pigment-free. The other grafts retain the original markings.

THE TRANSPLANTATION OF TISSUES

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D. APPLETON AND COMPANY
NEW YORK LONDON
1923

PRINTED IN THE UNITED STATES OF AMERICA

TO

HOWARD LILIENTHAL

MY FRIEND AND TEACHER

THIS VOLUME

IS AFFECTIONATELY DEDICATED

PREFACE

Although innumerable contributions to the subject of the transplantation of tissues have been made in the past fifty years a volume dealing with all the varieties of tissue grafts has not as yet appeared. This book was planned to deal comprehensively with the subject, with special reference, however, to the clinical aspect. It is in part a critical survey of the work that has been done in the transplantation of tissues and is in part based on personal clinical and experimental studies made during the past ten years. The volume cannot be classified as a text book on tissue transplantation for, in the analysis of the work of others, the author in not a few instances modifies considerably some generally accepted conclusions. Indeed, the subject, in its present immature stage of development, is not as yet ready for text book presentation. The main purpose has been to offer a clear presentation of the material from the viewpoint of its value in clinical practice at the present time. Topics that are now of purely scientific and theoretical interest have been subordinated to comply with this purpose, but they are sufficiently treated, it is hoped, for a well-balanced understanding of the principles of tissue transplantation.

Steadily growing in importance, the subject of tissue transplantation has become one of vital significance not only to those who are engaged in the various branches of surgery but also to physicians who would be conversant with its value and its expanding application in the practice of medicine. The text has been treated with a view of meeting this double requirement. The chapters are proportioned in keeping with the present practical value of the tissue grafts of which they treat. In each section a short analysis of the evolution of the work is given, followed by a discussion of the histology and the results of investigations in the transplantation of that tissue. Indications, contra-indications, the clinical value and scope, and concrete clinical applications then occupy the major portion of each chapter. Cases from personal experience and from that of others are presented to illustrate the value or the limitations of different procedures. The technic of transplantation of the various tissues is described in sufficient detail to render clear the various operative steps that are required. However, greater emphasis has been placed throughout on certain underlying principles in the firm belief that successful results are more dependent on these than on technical detail. The enormous bibliography on the transplantation of tissues had to be reduced to some extent but will be found to cover fully the work of the past twenty-five years.

Grateful acknowledgment is made to Dr. Samuel Hirshfeld for the preparation of the bibliography and index, and parts of the text. Without

his faithful collaboration this volume could not have been written. It is a welcome duty to express a deep sense of appreciation to those who have coöperated with and encouraged the author in his clinical and experimental investigations: Dr. George E. Brewer, Dr. William C. Clarke, Dr. William Darrach, Dr. Ransom S. Hooker, Dr. Howard Lilienthal, Dr. Fordyce B. St. John, and Sir Anthony Bowlby of the British Expeditionary Forces.

HAROLD NEUHOF

NEW YORK

CONTENTS

ILLUSTRATIONS

TRANSPLANTATION OF TISSUES

CHAPTER I

GENERAL PRINCIPLES OF TISSUE TRANSPLANTATION

In the past fifty years a progressively increasing degree of attention has been focused on the fascinating and age-old subject of transplantation of tissues. The interest of surgeons has been chiefly in the direction of clinical problems that called for solution by means of tissue transplantation, while the efforts of experimental investigators have been largely turned towards the determination of underlying principles involved in the transplantation of tissues. As a result, many interesting and important clinical contributions have been made and some basic principles have been gradually evolved.

The subject has become one of extraordinary complexity, owing in part to an almost incredible diversity of opinion expressed in the vast literature that has accumulated. The chief reason for much of the confusion that still exists at the present time lies in the fact that tissue transplantation, in its more modern aspects, is only partially developed. We are as yet ignorant of the meaning of many of the fundamental phenomena that are involved. Almost as important a cause of conflicting ideas is the lack of mutual understanding between clinical and experimental investigators. These two groups are often at opposite extremes in their viewpoints on many essential questions; for example, in the interpretation of such a basic matter as the viability of a transplant. It has been necessary to undertake the task of subjecting much of the literature on the transplantation of tissues to a critical analysis. In the presentation of the subject, personal experiences and impressions will be the basis for many of the statements to be made. Elsewhere our own interpretation of the results arrived at by others will be given. It is evident that there can as yet be no common agreement on many points, but we shall attempt as far as possible to offer the evidence in favor of the conclusions, tentative in many instances, that have been reached.

The presentation of the subject will be confined to the *free* transplantation of tissue; that is, the complete detachment of normal tissues from their bed and their transference to a new field in the same or in another host. The free transplantation of organs will be taken up only as far as some general principles are concerned, for this aspect of the subject is as yet in too undeveloped a stage for any detailed consideration. The experimental and clinical scope of tissue transplantation is truly unlimited but, despite the vast amount of work that has been done, the subject is as yet in an early stage of development.

CLINICAL AND BIOLOGIC SCOPE OF TISSUE TRANSPLANTATION

Investigations based on the transplantation of tissues have added to our understanding of biological phenomena in a number of directions. A beginning has been made towards the determination of the functional significance of some of the tissues, and of such organs as the pancreas and parathyroid glands, as a result of investigations in transplantation. Until the ultimate fate of transplanted tissues, to say nothing of organs, can be established, fundamental questions must, for the most part, remain open. Nevertheless, some vital biologic phenomena have been gleaned from the study of the regenerative power and the independent life of transplants. The results of tissue transplantation have added to our knowledge of the interrelation of the body tissues. For example, they demonstrate the influence of nerve impulses on the embryonal as well as adult cell growth, aid in the study of the phenomena of metaplasia, and contribute valuable information concerning the influence of physical forces on the growth of the tissues. Studies in transplantation have also thrown considerable light on the tumor problem. Some aspects of these questions will be taken up later but it will not be possible to enter into any great detail. They are mentioned here to indicate various directions in which investigations in transplantation of tissue are leading.

Great advances in modern surgery have been made possible as the result of the evolution of tissue transplantation, and our chief theme will be to indicate the various paths they have taken. To appreciate what has already been accomplished in this field, it need only be indicated that countless numbers of those wounded in the World War have been and are being greatly aided by the various forms of tissue transplantation. Had not this development of the subject come to pass, many of the lesions that were encountered would have offered insoluble problems in surgery.

Although the practical value of tissue transplantation has been established on a firm basis, it is of the utmost importance that the present limitations of our knowledge of the subject are clearly grasped. Otherwise, the actual significance inherent in grafting operations at the present time cannot be appreciated, and a precise evaluation of what may be anticipated from tissue transplantation is impossible. The lack of well grounded information on the transplantation of tissues has not infrequently led to inaccurate and bizarre statements out of all keeping with the evidence that is offered. For example, the clinical value of a tissue transplant may be great, despite an experimental demonstration of the necrosis of that tissue when transplanted. In other words, the practical value of a transplant need not correspond with the experimental evidence of its fate when transferred. Equally clear, however, is the fact that there must be an understanding of the meaning of both the clinical result and the experiment. No excuses are necessary for entering into details of experiments or clinical reports when they are warranted, for every effort should be made to attain a well-balanced viewpoint of the subject. The present state of our knowledge of the transplantation of tissues must be fully understood before further constructive work can be carried out.

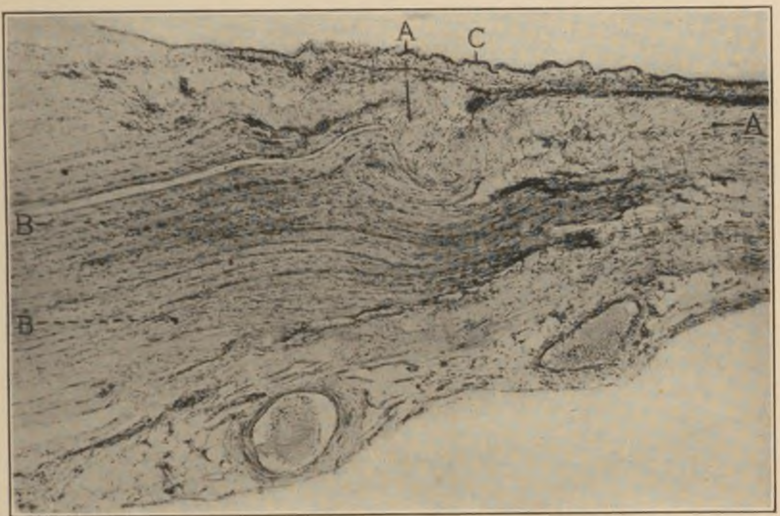

FIG. 1.—FIVE MONTHS AFTER A FASCIAL TRANSPLANT INTO A DEFECT OF THE DIAPHRAGM. To illustrate the intimate fusion between transplant and host. The altered graft, *A*, *A*, is interwoven with the musculature of the diaphragm, *B*, *B*. Note the overgrowth of pleura, *C*.

The Three Types of Transplantation.—Autotransplantation (autoplasty, autografting, autoplastic transplantation) denotes the complete detachment of one of the tissues of the body and its implantation into the same individual. Homotransplantation (homoplasty, isoplasty, homografting, homoiotransplantation, homoplastic transplantation, isoplastic transplantation) is the transference of a tissue from one to another individual of the same species. By heterotransplantation (heteroplasty, heteroplastic transplantation, zoöplasty) is meant the transference of a tissue from an individual of one species to an individual of a different species. There are no terms to denote variations in the type of homotransplantation and heterotransplantation. Thus the term homografting means the same thing whether or not it is made between blood-related human beings, and regardless of whether or not they are of the same race or color. This holds true for lower animals as well. A heterograft is as much a heterograft if made between dog and man as if made between monkey and man.

General Considerations of Results.—Much of the confusion that exists at the present time as to the results of transplantation is directly due to a loose and careless use of terms. What is meant by a "successful" transplantation? One writer may refer to the evidence of persistence of viability of the transplant for a long period, another to transient viability, and a third to a clinical success accompanied by absorption and

FIG. 2.—EIGHT WEEKS AFTER FASCIAL TRANSPLANT INTO DEFECT OF THE STOMACH.

Photograph from region toward center of defect. *A*, *A*, incompletely developed mucosa. *B*, bone plaque with periosteumlike layer, *C*, *C*. *D*, connective tissue in remainder of defect.

replacement of the graft. The various possibilities of the outcome of a transplantation should therefore be appreciated, and the result that was obtained in the given case specified, in order to clarify the involved state of the subject at the present time. A transplant may become encapsulated like any foreign body and play a merely passive rôle or even act as an irritant. It may heal in place, to become absorbed and gradually replaced by tissues laid down by the host. Lacking the fundamental knowledge of what transpires, the term "physicochemical stimulus" can be roughly employed to indicate the action a graft may have upon the host, the result being the replacement of the transplant by tissues closely resembling it. Until a better understanding is reached, physicochemical factors must also be held accountable for a replacement of the transplant that may occur, wherein the tissues laid down by the host in and about the graft differ considerably from the graft itself. For example, I have shown that a section of fascia transplanted into a defect of the bladder or the stomach is replaced

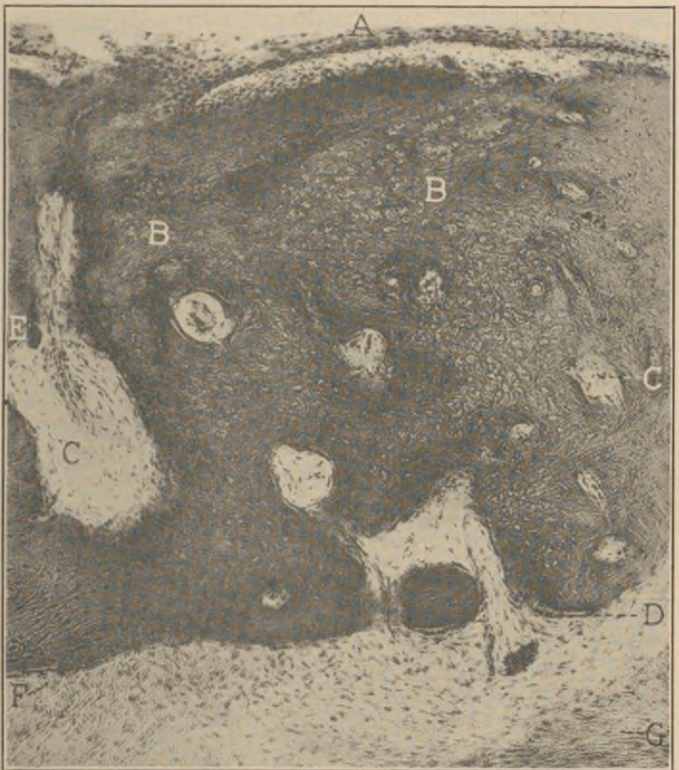

FIG. 3.—SEVEN AND ONE-HALF WEEKS AFTER FASCIAL TRANSPLANT INTO DEFECT OF BLADDER.

This shows the details of the tissues occupying the defect. *A*, layer of epithelium. *B*, *B*, clusters of cartilage-cells in the bone. *C*, *C*, bone marrow. *D*, row of "osteoblasts." *E*, osteoclast. *F*, osteoid tissue. *G*, smooth muscle.

by connective tissue in which bone and even cartilage may be laid down. This apparently can occur only as the result of metaplasia, and metaplastic processes are to be considered as always playing an important part—in our opinion, the preponderating rôle—in the ultimate fate of most transplanted tissues. In the true sense a transplantation is "successful" only when the graft remains permanently viable and retains indefinitely its original function. We have been unable to trace in detail all of the many hundreds of claims for successful transplantations in this sense. It may be stated at once that the great majority of the large number that has been investigated does not present conclusive evidence to support such assertions. The possibility of truly successful transplantation can be conceded in only relatively rare instances at the present time. The reasons are as yet unknown. In general, it may be said that successful transplantation, in the real sense of the term, does not exist. Whether the cause lies in imperfect technic, lack of knowledge of biologic phenomena, or elsewhere remains to be proved.

Elements that Influence Results—*Characteristics of Different Species.*—Although the underlying factors are not understood, it is now recognized that the various animal species do not respond in the same way to tissue transplants. Some species react more favorably to transplants than others; in general, the lower the animal in the scale, the greater the tendency toward ideal results after transplantation. However, allied species may present wide differences and higher species may

FIG. 4.—TRANSPLANTATION OF CONNECTIVE TISSUE.

Female mouse, two and a half months after transplantation of connective tissue derived from its own embryo. At autopsy an embryoma was found, with a cyst in its anterior portion (Schoene).

exhibit more favorable results than lower. For example, autotransplantation of skin succeeds much better in mice than in rabbits. It would appear that different species have different resistances, indicated by the varying responses to tissue grafts. Variations in the results after transplants of normal tissues also hold true for transplants of tumor tissues in the different species.

Stage of Development of the Tissue—Embryonal Transplantation.—Some results of the transplantation of embryonal tissues have a significant bearing on the results that may be anticipated from the grafting of adult tissues. In plant life the almost unlimited success in transplantation appears due to the fact that buds approximate embryonal tissues or organs, the transplanted cells thus being capable of reproducing the entire organ. The lowest forms of animal life present a similar phenomenon wherein the whole may grow from small tissue fragments. Transplants of undifferentiated embryonal tissue of higher animal species present the same tendency towards growth with differentiation. For example, the development of embryonal bone in the anterior chamber of the eye following implantation of fragments of embryonal tissue has been observed.

Many remarkable phenomena of independent growth have been seen after the transplantation of specific embryonal tissue or of parts of embryos. Various forms of tumorlike masses presenting differentiation of the embryonal tissue have grown from such grafts, especially after intraperitoneal implantation. The results of embryonal transplantation are, of course, incomparably more favorable for further growth than those of transplantation of adult tissues. Even here, however, unlimited success is not the rule. Sifting the large amount of work that has been done, we find that the variations in results are not haphazard. In fact, a study of the variations leads to the formulation of some laws of great

FIG. 5.—FEMALE MOUSE WITH SKIN TRANSPLANTED FROM ITS NEWBORN OFFSPRING.
Result after a half year. Note the growth of hair and the suggestion of development of auricles (Schoene).

significance in their application to the transplantation of adult tissues. They may be stated as follows:

1. The less differentiated tissues show a more active growth both qualitatively and quantitatively than the highly differentiated tissues.

2. The wide range of successful embryonal transplantations does not include nervous tissue.

3. Only organs (glands) not intimately linked with the nervous system are transplantable in the true sense.

4. Organs loosely joined with the nervous system are not as transplantable as sections from them.

5. Growth of transplanted embryonal tissue does not continue indefinitely. A stationary period is reached and finally much or all of the transplant disappears as a rule.

It will be shown that these laws, derived from a study of the results of embryonal transplantation, are far-reaching in their application to the transplantation of adult tissues and go a long way toward defining the limitations of tissue transplantation at the present time.

INDEPENDENT VIABILITY OF TISSUES

The modern methods of tissue culture, inaugurated by Harrison, have disclosed the fact that tissues detached from their host may live and grow in plasma, lymph, or even in simple salt solution. Not only is this true of adult tissues from the lowest species and of embryonal tissue, but also of adult tissues from the highest species. It has also been demonstrated that tissues can remain in a state that may be termed one of suspended animation for many days (by keeping them at a low temperature) and that they may continue to live and to grow after such periods of time when placed in appropriate media.

There are considerable differences in the independent viability of the various tissues. This was known before the advent of tissue cultures. Thus, Ljuenggren and others have shown that epidermis may remain viable for two or three weeks or longer, some of the connective tissues such as periosteum for about the same period (Busse), whereas the independent viability of nerve or kidney tissue is very short. When reports are made of so-called successful transplantations (not tissue cultures) of many varieties of highly differentiated tissues after having been preserved in cold storage for days or weeks, a careful scrutiny of the evidence will usually show that the transplant has not remained viable but has been replaced by tissues from the host. The existence of an independent viability of tissues is, of course, not negated by proof of its limitations; in fact, there can no longer be any doubt on this question for the phenomenon of independent viability is clearly established. However, in view of some far-fetched conclusions that have been drawn from studies in tissue culture, it cannot be too strongly emphasized that what happens in this relatively simple situation is not to be interpreted as a guide to what will occur to transplants in a living organism. Specific substances essential for life in the body are not required for tissue culture "life." In tissue cultures, it is only the simplest manifestations of life that are chiefly observed, and continuation of life is possible only by continuously replanting the newly sprouting cells. Even under the most favorable circumstances (by the use of autogenous plasma, etc.), tissues do not fully ripen in cultures. Reactions to transplants in living organisms, due to phenomena of immunity and to other chemical and physical changes upon which the outcome of so many transplantations vitally depends, do not come into play to any appreciable extent in tissue cultures. Thus the observations made in tissue cultures cannot be indiscriminately applied to tissue transplantation, especially if the limitations we have indicated to be inherent in the infinitely simpler tissue cultures are recognized.

Of the complicating elements that arise when grafts are implanted in a living organism, nearly all tend to reduce the period of viability of the transplant. Their consideration comprises an analysis of the elements that enter into all transplantations. A discussion of these factors will now be taken up.

Autotransplantation—*Viability of Transplants.*—It is now universally recognized that the maximal chances for success, as far as viability is concerned, attend autotransplantation. The chances are much less in homotransplantation, and least in heterotransplantation.

The meaning of viability should be clearly grasped. It refers to a living state of the transplant. If the transplant is an organ there must be well-defined evidence, both anatomically and functionally, of its living condition. A tissue transplant should present physical and chemical characteristics by which it can be identified as that tissue in a living state. Upon microscopic examination, organ or tissue transplants must show at least parts of the normal organ or tissue, with the cells well stained and all the other evidences of cell activity. Vital tissue staining is of value as a check on the ordinary tissue stains. With these criteria of viability in mind, it is apparent that viability after clinical transplantation can but rarely be proved. Most of the evidence must be obtained from animal experimentation and by analogy. Confusion on the all-important question of viability of tissue transplants in animal experimentation still exists at the present time. A significant reason for this is the fact that different and sometimes very elastic criteria of viability are formulated by various investigators. Transplants, reported viable by some authors, are not accepted as such by others.

The single factor of *technic of operation* has a profound influence on the results that are obtained. It will be shown how greatly such elements in operative procedure as asepsis, establishment of hemostasis, avoidance of dead spaces, etc., affect the outcome of transplantation in the human being. The results in animal experimentation are unquestionably influenced in the same way. There is every reason to believe that varying results, described by different investigators carrying out identical experiments, are not necessarily due to different interpretations, but can often be ascribed to differences in technic. Surgeons appear to have been content to accept unqualifiedly the results of complicated experiments in transplantation, sometimes performed by investigators untrained in operative technic. The danger of many pitfalls is evident if results obtained under such circumstances are to be applied to clinical surgery.

Other causes for false interpretation lie in incomplete observations and in observations over too brief periods of time. A striking illustration may be taken from our own experience. In a series of experiments, fascia lata had been used to bridge defects of the walls of the great arteries. Experiments terminated shortly after operation presented evidences of persisting viability of the transplant; those terminated at a middle period presented partial viability and some signs of replacement of the transplant; and those continued from six to nine months showed the transplant completely replaced by a connective tissue derived from the host.

For these and other reasons the fundamental question of viability, upon which the whole subject of tissue transplantation depends, is in an unsettled state and the remarks on autotransplantation, homotransplantation, and heterotransplantation must to that extent be accepted tentatively. It is evident that a large part of the literature on the question of viability of autotransplanted tissues does not permit of

FIG. 6.—CROSS-SECTION THROUGH THE CAROTID ARTERY AT THE SITE OF THE DEFECT REPLACED BY A FASCIAL GRAFT.

Microphotograph taken six months after operation. The graft occupies the circumference below *A*, *A*. *B*, dense connective tissue with irregular but smooth free surface, probably following a parietal thrombosis. *C*, the fascial graft, largely replaced by fibrous tissue. *D*, *D*, silk sutures.

critical analysis and much of the supposedly fundamental work will have to be done again if the facts are to be known.

However, there can be no question of the possibility of viability of autotransplants for an indefinite period. To choose one group of the many impressive illustrations, the prolonged viability of skin grafts may be mentioned. Any doubt on the question of viability of tissues must be dispelled by the remarkable experiment reported by Zaaijer in 1914. He described a dog alive and well more than six years after autotransplantation of a kidney to the thigh by suture of its vessels to the femoral vessels, the other kidney having been removed. The animal, with its single transplanted kidney, showed no abnormalities other than a trace of albumin in the urine. Theoretically one may argue that all autotransplants should evince permanent viability since indefinitely prolonged life of some transplants has been demonstrated. This may and indeed should prove to be the case in the future. With our present limited knowledge, however, the fact remains that permanent viability cannot be anticipated in the great majority of cases in which autotransplantations are performed. In general, autografts present some degree of transient viability and it appears to be this factor that places autotransplantation nearer the ideal than homotransplantation and heterotransplantation, not only on the basis of histologic examination but also on that of the clinical result. To conclude briefly, the probable fate of an autotransplant can be said to be one of varying viability with gradual replacement by tissues from the host and ultimate disappearance of the graft.

Homotransplantation—*Tissue Compatibility*.—For the past thirty or forty years a tremendous effort has been made by investigators everywhere to place homotransplantation upon a firm basis in clinical surgery, for it has been fully realized that this is the ultimate goal of tissue transplantation in the human being. The results have not as yet been encouraging. Homotransplantation has a considerable degree of success in the lower forms of animal life. Among mammalia the successes that bear careful scrutiny are few and far between, and are chiefly in the transplants of embryonal or young connective tissue. It would also appear that, for some unknown reason, the outlook for success in homotransplantation is better in some species than in others. In human beings and among the mammalia, only very brief viability can be anticipated under ordinary circumstances. The clinical importance of this lies, of course, in the fact that no great reliability can be placed on the durability of such a graft. It may be absorbed before adequate replacement by the host takes place, encapsulation may occur, or the graft may act as an irritating foreign body. These practical drawbacks to the application of homotransplantation do not exclude its application to the human being but sharply limit the usefulness of the only means of transplantation that holds out the greatest degree of hope.

The one feature of homotransplantation that has been almost completely ignored is the question of tissue compatibility or incompatibility, and yet this appears to me to go to the root of the problem. When von Dungern and Landsteiner discovered the existence of iso-agglutinins in human blood, and found that individuals fell into several groups, the safe transfusion of whole blood was made possible. Transfusion of blood is a form of tissue transplantation and there can be no question of viability, for a period of time at any rate, when blood is transferred from an individual in one blood group to another in the same group. Here, then, we have a homotransplantation attended with a measure of success because of blood compatibility. It appears to us to be within the realm of probability that many other tissue homotransplantations can succeed on the same basis. A beginning has already been made in homotransplantation of skin. A few recent reports indicate that transference of skin from one human being to another will succeed if the individuals are in the same blood group and fail when they are in incompatible blood groups. I have made the same observation in some cases (see Chapter II). If this proves to be universally true for skin grafting, may it not prove equally true for other homotransplantations, not only of tissues but also of organs? It is my firm belief that further work along this line will go far towards establishing a method for successful homotransplantation in the human being. Unfortunately, parallel experimental observation cannot be made readily on lower animals, for their blood group characteristics are not as clearly defined as in man. We have given careful consideration to the subject and, after considerable investigation, have come to the conclusion that the ordinary laboratory animals do not lend themselves to work along this line. Improvement in the methods of blood grouping may lead to better results than those we have obtained in our experiments.

Heterotransplantation.—Little can be said on the subject of heterotransplantation at the present time. Although remarkable results can be obtained in plant experiments, and heterotransplantation of undifferentiated embryonal tissue may have some measure of success, there is no immediate outlook for persisting viability of heterotransplants in the higher animal species and in man. The transplant undergoing too rapid necrosis and absorption for adequate replacement, no dependence can be placed on it if viability is desired. At the same time, some heterotransplantations, especially of bone, are of considerable value for practical purposes in human surgery when prolonged persistence of the graft is not required.

BIOLOGIC PHENOMENA ASSOCIATED WITH TISSUE TRANSPLANTATION

The characteristics of the cellular growth that occurs about grafts will be taken up in the description of the transplantation of the various tissues. In this place I wish to discuss the biologic phenomena that are involved.

That a vast difference in such phenomena exists between autotransplantation, homotransplantation and heterotransplantation, has been indicated, but the reason for these differences is not so evident. When the cellular zone about a disintegrating heterograft is examined microscopically, the appearance is found to resemble closely that seen in infected wounds. Leukocytes in great numbers are also found about homografts, although to a lesser extent; on the other hand, the leukocytic reaction is relatively slight in autotransplantation. Various causes have been invoked in an effort to explain the differences. Some may be mentioned: differences in the chemistry of the tissues of donor and recipient; the influence of agglutinins in homotransplantation; nonassimilability of heterotransplants and homografts as compared with an assimilability of autografts; disturbances in osmotic pressure because of differences in salt content between tissue of transplant and that of host. The existence of a tissue specificity may prove to be the essential factor, as suggested in Ehrlich's work. According to some investigators, there occurs an active immunity to tissues of foreign species that are introduced, and this results in the destruction of the transplant. When such an immunity does not normally exist it may be induced by introducing various substances (extracts of the transplant, adult chicken spleen for chicken embryos, etc.). Perhaps the best illustration of general as compared with local immunity is seen in pregnancy, for transplantation experiments are found to fail in pregnant animals under conditions in which they succeed in nonpregnant ones. It is impossible to enter here into the details of the various theories that have been advanced to explain the differences in the results of heterotransplantation, homotransplantation and autotransplantation. Enough has been said to indicate that the cause, not clearly understood at the present time, is probably based chiefly on biologic (physicochemical) phenomena.

In addition to its severance from a natural environment, the transplant is also disconnected from its blood and nerve supply. The inevitable biologic effect on the graft is evident. Carrel, in introducing his methods of vascular suture, believed that the blood supply to the graft was of more importance than its nerve supply. Unquestionably an immediate blood supply to the graft reduces the extent of necrosis that may occur, particularly in the central portion of the transplant. This holds true more particularly of autotransplantation, for in homotransplantation death and replacement of the graft occurs despite blood-vessel suture in the experiments that have been conducted up to the present time. Since independent viability is, as has been shown, a characteristic of the transplant, it is evident that the graft may remain viable until vascularized by the host. In fact, this must be what happens regularly in autotransplantation without blood-vessel suture, otherwise the outcome would be a totally different one. Not minimizing the vital importance of blood-vessel suture in the transplantation of whole organs, we would nevertheless state our belief that it has proved of comparatively little biologic importance in the transplantation of tissues.

Severance of the nerve supply, on the other hand, must have a profound bearing on the life activities of the transplant (see transplantation of the adrenal gland). It is unnecessary to point out the result of loss of nerve supply and nerve control on the function of the various parts of the body under ordinary circumstances. Similar results must inevitably follow the detachment of a transplant from its bed. Only when the problem of conducting an immediate nerve supply to a detached tissue has been solved can normal biologic phenomena be anticipated in the transplant. It is only under such conditions that continuance of perfectly normal function and permanent viability can be visualized.

The question of severance of nerve supply has an important practical bearing on the selection of tissues for transplantation. As would be expected, the more intimately a tissue is connected with the central nervous system the less its viability when detached, the less its tendency to function as such, and therefore the less its general adaptability for transplantation. The comparatively successful results of autotransplantation of the kidney must be ascribed to extensive autonomic nerve centers and are to be compared with the unfavorable results of transplantation of most of the other organs. In the simpler connective tissues, such as fat or fascia, the nerve supply is a very secondary factor. They are not as dependent on nerve impulses for some degree of persistence. It is this biologic fact that places the simpler, less differentiated tissues in the most serviceable class for purposes of transplantation.

The phenomena occurring in the transplant and the host having been noted, the cellular reaction about the graft may now be outlined. Reference has been made to the leukocytic invasion of heterotransplants and to its existence to a far lesser extent in autografts. Considering the latter alone, the evidences of efforts at repair appear early and are almost identical with the phenomena of repair in a clean wound. A fibrinous exudate attaches the transplant to its bed shortly after the graft has been placed there. The layer of exudate becomes occupied by leukocytes and fibroblasts and is gradually replaced by a vascular connective tissue containing many round cells. From this young granulation tissue there sprout vessel buds that penetrate the transplant. It is as yet a moot point whether or not these vessels anastomose with those of the transplant. There can be no question, however, of the more important rôle in circulation played by the vessels of the host as compared with those of the graft.

The evidences of degeneration in the graft vary with the tissue, the bed into which it has been placed, etc. Within a few days, however, degenerative changes in the central portions of the graft usually can be discerned. The replacement phenomena from the host now begin. An interesting fact is that these vary in rate and extent according to the degree of persistence of the autograft. In a sense, the graft may be considered a passive regulator of the rate of repair. From a biologic point of view this would appear to be the main action of the autograft. With the gradual replacement of the graft by connective tissue, the variations begin, depending on different physicochemical factors. The tissues occupying the site of the transplant are laid down in a thicker or thinner layer, depending on the degree of strain to which they are subjected; angles tend to be smoothed out, and other physical changes occur. When grafts are placed over body surfaces, adjacent epithelium of the host spreads over them to cover in the bare areas. In satisfactory transplantation I have noticed that the slow rate of replacement usually permits the newly deposited tissue to gradually fill the tissue interstices of the graft. As a result, relatively little, if any, contraction of the area originally occupied by the graft is usually the rule. This is, of course, of great practical importance. Another phenomenon is the mimicry of the original structure of the transplant by the tissue replacing it and this is the cause of many false interpretations of viability of transplants. The histologic appearance is all the more remarkable because the tissue replacing the graft is in general an undifferentiated tissue. On the other hand, evidences of metaplasia are not infrequently seen in some of the tissue that replaces the graft. Herein lies another common source of error in the interpretation of viability, particularly when the replacing tissue is barely distinguishable from the original graft. Indeed, when the final stages apparently show the graft in permanent preservation, it is occasionally necessary to study the intermediate stages of experimental observations to establish disappearance and replacement of the transplant. Metaplasia is a prominent and frequent manifestation in some situations, uncommon and in the background in others, apparently depending on the physicochemical factors that are at work. Its diversified appearances will be described in the sections devoted to the transplantation of the various tissues.

The Rôle of Function in the Fate of the Transplant.—This question is as yet in a very unsettled state. At one extreme we find those who believe that functional activity is required for persistence of the transplant. To mention a single instance, Halsted described persistent functional activity in autotransplants of parathyroids when the remaining ones were removed, and early disappearance of the transplants if the remaining ones were left in place. At the other extreme there are those who believe that the rôle of function has no bearing on the fate of the transplant. An example of this is the work of Judet, who transplanted whole joints into the soft parts and found them to persist as such when there was evidently no function to perform. Many instances may be mentioned in which transplants disappeared despite a vital "necessity" for their retention, and an equal number can be quoted in which transplants persisted after insertion into regions where they were not needed.

It would lead too far afield to enter into the numerous theories that have been advanced. We think it is safe to say that the changes that occur in a transplant, leading ultimately to its disappearance in most cases, are the same whether or not there is a "functional call." A section of bone introduced into a bone defect will disappear in about the same way as a section of bone placed under the skin. But the *response of the host* is different in the two cases, and this appears to us to be the crux of the matter. In the one case there will be new bone laid down by the host in and about the transplant in the bone defect, perhaps partly from physicochemical stimulation by the disintegrating transplant, perhaps partly from a "functional necessity" to repair the weak place. We have reported the metaplastic appearance of bone in and about disintegrating fascial transplants in gastric and vesical defects and have not seen such deposits about fascial transplants into other hollow viscera. The acid medium seems to have been the decisive factor to account for the differences in the outcome of these experiments. Therefore, it may be concluded that the response of the host

FIG. 7.—FASCIAL TRANSPLANT INTO A DEFECT OF THE BLADDER.

Taken four months after the transplantation to show the large marrow spaces and the extreme development of bone marrow.

to a transplant is a varied one; the questions of function, the nature of the field, physicochemical factors have an important rôle, but the fate of the transplant does not depend essentially on function.

FACTORS INFLUENCING CLINICAL RESULTS

Some of these elements have been considered. There are others as yet too obscure to be dealt with at the present time. An important fact to be remembered is that even an autotransplantation of a simple tissue may fail when all known requirements are fulfilled and the situation appears ideal for success. When a standard surgical procedure offers a favorable outlook for a satisfactory result, it should always be chosen in preference to one involving the transplantation of a tissue. There are some general factors that loom large as influences in the result of every transplantation and these will now be considered.

The size of the transplant plays a part in its fate. The smaller the transplant, the more apt it is to remain viable for a time. Only the peripheral portions are preserved in part, as a result of their vascularization by and contact with the body fluids of the host. Large grafts may be more successfully implanted by blood-vessel suture, but the fact remains that the smaller the transplant the better the outlook. This has its practical significance in clinical work. If a solid bone graft is not required in a space, multiple small bone fragments should be employed. If a mass of fat is to be used to fill a depression, a more favorable result can be anticipated by dividing it into several fragments. The shape of the transplant also influences the result, a thin flat graft being better than a cylindrical or cuboidal one. Other things being equal, a sheet of fascia lata rolled up is more desirable as a transplant than a section of tendon of the same dimensions.

The more highly differentiated and the more vascular the tissue, the less favorable it is for transplantation. Theoretically, highly differentiated tissues such as nerve, muscle, or portions of organs would be ideal if their function could continue when they are transplanted. As has been shown, however, it is just such tissues that possess the most transient viability when detached from their source. Undergoing rapid degeneration, they do not persist long enough for vascularization by the host and usually fail in the functional purpose for which they were grafted. For practical purposes highly differentiated tissues are only to be considered if a temporary functional action is desired, and this is a requirement that rarely arises.

If skin, with its prolonged independent viability (two to three weeks), is to be classified as a highly differentiated tissue, it forms the one great exception to the rule. The fundamental principle, that the simplest tissues are the most favorable for transplantation, holds true.

The use of the "postage stamp" graft of muscle or fat for the control of bleeding areas offers an excellent illustration of one of the characteristics of a graft, namely, its adhesive quality. Were this not so, a dead space would exist between the transplant and the surrounding tissues of the host with an inevitably unfavorable outcome. The difference between the prompt adherence of an autograft of skin and the delayed adherence of a homograft is well known and has been the prominent reason for the difference between success and failure in this field.

Finally, the delicate state of a tissue detached for transplantation should be emphasized. It is highly susceptible to unfavorable influences such as rough handling, drying, contact with chemicals, etc. This will be taken up again in the discussion of technic. It may be stated here that, because susceptibility to external influences is one of the striking characteristics of a transplant, a fastidious technic is one of the most essential features of successful tissue transplantation.

The Bed for the Graft.—Some aspects of this question have been discussed. In general it would appear that the more closely the new environment resembles that of the transplant the better the outlook for a satisfactory clinical result. Thus skin grafts are more apt to "take" on the surface of the body, in the region of other skin areas, than elsewhere; bone grafts in bone defects, etc. Some observers believe that a specific chemistry in the field is an important element in accounting for the replacement of a graft by analogous tissue. In this theory it is held that the disintegration of the graft releases substances stimulating the production of similar tissues by the host.

The necessity for sufficient nourishment of the transplant from the area receiving it, is evident. If there is no adequate supply of blood or lymph at an early stage, a satisfactory transplantation cannot ensue. Therefore a freshly denuded area is a much more desirable field than one covered by old granulation tissue or composed of cicatricial tissue. For example, skin grafting on a recent wound is more apt to be successful than one on an old granulating wound. When the nourishment of the field to receive a transplant is impaired, it is better to wait if possible and attempt to improve the circulation of the part. Exposure to sunlight or to the quartz lamp for this purpose is employed by Lexer. We have found it of value to prepare doubtful fields by the use of massage, frequent hot baths or the application of heat, and passive hyperemia (by the Bier bandage) and baking where applicable, and would advocate such systematic preliminary treatment for areas that are largely occupied by cicatricial tissue.

Rigid asepsis, on the one hand, and elimination of antisepsis, on the other, are essential not only in the detachment of the graft but also in the preparation of the field to receive it. A slight infection may be followed by the expulsion of the graft. It is, however, sometimes necessary to practice transplantation into infected fields, and satisfactory clinical results have occasionally been obtained under such circumstances. For example, we have reported clinical successes following transplantation of fascia lata into defects of the urethra and of the trachea. The general rule, however, should be to withhold transplantation when the field is infected.

Another essential element in the preparation of the field at the time of operation is perfect hemostasis. Hemostasis, as ordinarily established at operations, will not suffice. If there is oozing at the time the graft is applied or inserted, a layer of blood-clot will, of course, separate the transplant from the field receiving it. The primary tissue contact, so desirable for the ultimate result of the transplantation, is incomplete or does not exist and vascularization, etc., must proceed through a zone of organizing (and probably obstructing) blood-clot. Unquestionably many transplantations, that would otherwise have been satisfactory, have failed because of the neglect of this single precaution. The steps to be taken to control oozing are not complicated and, a tissue transplantation ordinarily not being an urgent operation that has to be done with great speed, all the required time can be taken for the absolute control of bleeding and oozing. Manifestly an Esmarch bandage should not be employed in transplantations on the extremities.

One step we advocate for the control of oozing, is the administration of sodium citrate. We have found that the introduction of this drug in adequate dosage shortens the normal coagulation and bleeding time approximately one-half. The change begins shortly after the injection and reaches its peak in about one-half hour. The period of greatly shortened coagulation of the blood persists for about two hours, with a gradual return to the normal in twenty-four to forty-eight hours. The optimal dosage for adults is 9 grams of sodium citrate (C. P.), dissolved in 30 c.c. of distilled water (a 30 per cent solution). When given intramuscularly (half the dose into each buttock), the method of administration is free from danger, as we have demonstrated in several hundred cases. We believe that the addition of the sodium citrate injection to the ordinary means of establishing hemostasis in the wound should prove of definite value in the essential step of properly preparing the field to receive the transplant.

Maximal tissue contact between graft and field being an important element in satisfactory transplantation, dead spaces should manifestly be reduced to a minimum. For example, when a cylindrical graft is in contact with the field at both ends alone, or a flat graft bridges a defect with only marginal contact with the host, a satisfactory result cannot be anticipated. Emphasis has not been placed on this question of the reduction or elimination of dead spaces, and yet I consider it an essential practical feature in transplantation. It is not always possible to avoid some gaps that will be subsequently occupied by blood and lymph, and rules for their avoidance cannot be laid down, but by careful planning before and during operation, they can often be largely or entirely avoided.

Special considerations will come up in the postoperative care of the field with its transplant in accordance with the nature of the case. In general it may be stated that immobilization is required for a time after operation to permit of firm adherence between graft and host. This may be undesirable under certain circumstances, as in transplantations for tendon defects, but ordinarily it should be employed.

A point we wish to make and lay stress upon is that many patients on whom tissue transplantation is practiced are in debilitated physical condition from their disease at the time of operation. Besides attention directed toward improvement of the physical condition before operation, vigorous efforts should be made after operation to improve patients whose general condition is unsatisfactory. Reparative processes in the operative field unquestionably keep pace with the general physical condition, and, therefore, it is not enough to be content with a satisfactorily conducted transplantation procedure alone. We recall a case of bone grafting for the defect following resection of the femur for osteosarcoma, in which we believe that a transfusion of blood several days after operation aided greatly in the successful result of the transplantation.

Another therapeutic measure, not only for the improvement in the general condition, but also for improvement in the reparative processes in the operative field, is the use of sunlight. Several years ago, I reported the results of some experiments in which the acceleration of repair after fracture by the use of sun exposures was demonstrated. It is reasonable to assume that a similar result would be obtained after transplantation operations, and particularly in bone grafting.

The Effect of Age, Physical Condition, and Disease.—The greater viability and proliferative power of embryonal tissues has been pointed out. Destruction of cells occurs, of course, as soon as life begins. In the human being youth can be characterized as the phase of life in which the regenerative phenomena are most pronounced. This power to build up diminishes as the years go on. Old age may be described as the stage in which the replacement of cells and tissues can no longer keep pace with their destruction. One may safely assume that the replacement phenomena about a transplant, dependent upon the cell activity of the host, would be more active in the young than in the old. Clinical observation strongly supports this assumption. Old age, measured more by the physical state than the number of years, is a general contra-indication to any transplantation other than an imperative one. This applies not only to the recipient but also to the donor of the graft, for minimal viability must exist in the graft taken from an old individual. Schoene demonstrated the effect of age in some experiments with skin transplants, in which he showed that grafting from offspring to mother was successful whereas grafting from mother to offspring failed.

Deterioration in physical condition in the recipient of a graft has an unfavorable effect on a tissue transplantation. This was indicated in the discussion on the field receiving the transplant. In homotransplantation it would appear to be equally true that grafts taken from debilitated donors prove less satisfactory than would otherwise have been anticipated. There are a number of reports in the literature in which failure has been ascribed to such a cause, but the evidence given is not sufficient to prove that this was the sole element involved. As regards autotransplantation there can be little question as to the greater proportion of successes in well-nourished individuals.

The existence of some disease, especially syphilis, tuberculosis, and low-grade sepsis, unquestionably results in interference with adequate repair after autotransplantation. Grafting would naturally not be performed during active stages of such diseases and if they have existed, it is essential to obtain clear evidence of a complete control of tuberculosis or syphilis. We recall an instance of bone transplantation for an un-united fracture of the tibia in a patient who had been previously treated for syphilis. A phlegmon developed in the operative field, the whole wound broke down, and healed only after prolonged antiluetic therapy. If operation is indicated, other operative procedures than those involving tissue transplantation are preferable under such circumstances. A recent experience furnishes a striking illustration. The patient presented a granulating area covering a large defect on the sole of the foot following an accident. He had been treated for syphilis years before but his blood showed a positive Wassermann reaction. Antiluetic treatment was given. The operation consisted in the preparation of the field and the detachment of a pedicled flap from the opposite calf that was sutured in place. The base of the flap was divided ten days later. There was some marginal necrosis of the flap but healing was satisfactory and the outcome good. On the other hand, complete failure followed the autografting of skin over the area on the calf from which the flap was taken. Thus a pedicled flap operation succeeded, whereas a free transplantation failed.

The Indications for, and the Technic of, Transplantation.—The indications for, and the technic of, the transplantation of various tissues will be discussed in detail in the sections that follow. Before that is done, the general underlying principles should be summarized.

Tissue transplantation cannot as yet be classified as a standard surgical procedure. Indiscriminately or carelessly practiced as an operative measure, failure will more and more commonly be the sequel, and a method of great value in surgery may fall into disrepute. One can already sense a drift in this direction, interspersed though it is with extravagant claims. We have made an effort to indicate what may be anticipated from tissue transplantation at the present time, and no more can be expected unless there is definite evidence that it is justifiable to expect more. A tissue transplantation may fail when all the known essentials for its success exist. This fact should not be lost sight of, for it incorporates an essential indication for tissue transplantation. A transplantation should be employed only when it is evident that other surgical measures will not satisfactorily solve the problem. It should be practiced with the clear realization that failure may render the situation worse than was the case before operation. The contra-indications, therefore, should not be forgotten. They comprise, chiefly, such diseases as tuberculosis, syphilis, old age, debilitated conditions from previously existing disease, and the existence of infection in the area for the reception of the graft. Slighter degrees of infection may be compatible with transplantation under special circumstances. Dense scar tissue in the field to be grafted renders the outcome problematical and, albeit not a contra-indication, is an unfavorable factor.

Some aspects of the technic of transplantation have been taken up in the discussion of the biology of the graft and the field. The necessity for rigid asepsis, both at the field from which the graft is taken, and at that to which it is transferred, is clear. Clean, sharp, gentle dissection reduces the degree of trauma in both situations.

The susceptibility of the graft to external influences has been indicated. Crushing by forceps, contact with chemicals, cooling, drying, in short, any factor interfering with its vitality, is to be avoided. It is best, whenever possible, first to prepare the field for the implantation and then to detach the transplant and transfer it directly to the prepared area. We believe this to be preferable to placing the graft in moist gauze or in some solution (even normal salt solution).

A method we employ for the detachment of such transplants as fat and fascia minimizes the degree of trauma at removal and aids in their proper placement with least handling in the receiving field. It will be detailed in the section on fascial transplantation. The technic consists, essentially, in passing three or four sutures at opposite points within the margin of the planned line of section, and then cutting around these points in the pattern that has been decided upon. The transplant is lifted to the prepared field by the sutures with their attached needles. These sutures are then passed through the tissues of the recipient in the desired situations and are tied. Thus the graft is placed in position without handling and is ready for any additional fixation that may be required.

Whenever sutures are used to fix the graft, the finest material should be employed. Thick strands result in unnecessary reaction in the surrounding tissues. Although absorbable suture material is most commonly used, we acknowledge a preference for fine white silk. In the microscopic examinations of sections in experimental work, we have frequently noted that the silk strands become sharply encapsulated without any appreciable evidence of irritation of the adjacent tissues. The utmost contact between graft and host being desirable, continuous sutures are in general preferable to interrupted ones. Whatever type is employed, it is essential that the stitches should not be placed too near one another. The chances for interference with viability of the graft, and, particularly, for marginal necrosis, increase in direct proportion to the proximity of the sutures and the amount of suture material that is employed. That tension is not to be put on sutures passed through a graft should be considered axiomatic in transplantation work. We would emphasize this as the most essential single precaution to be taken to avoid interference with the viability of the graft. It is impossible to visualize any process other than necrosis going on in those parts of the graft placed under undue tension. Tension on the tissues of the field receiving the graft interferes with the nutrition of the transplant and the surrounding processes of repair. Nevertheless, enough traction should be applied, when sutures are used to fix grafts of soft parts, to avoid wrinkling or displacement.

In the discussion of the biologic phenomena occurring about the transplant, the necessity for perfect hemostasis in the receiving field was dwelt upon. It was pointed out that a layer of blood-clot between host and graft meant interference with nourishment to and processes of repair about the graft. The use of an Esmarch bandage was shown to be undesirable. Ordinary hemostasis does not suffice. The transplant should not be placed in position while oozing is still going on. If necessary, the wound should be packed and repacked until bleeding has been controlled. As a valuable adjuvant for the control of bleeding we advocated the use of sodium citrate and described the method of its administration. The use of tight bandages after operation to control oozing in the wound can result only in interference with the nutrition of the transplant. The use of local (infiltration) anesthesia for operation is usually not desirable, for bleeding, temporarily checked thereby, may begin after the wound is closed.

The transplant should fit snugly and smoothly in its bed so that the broadest possible approximation of the two exists. The biologic and practical importance of this has already been emphasized and the danger inherent in dead spaces has been pointed out. Rules cannot be laid down, for no two situations are alike, and the resourcefulness and ingenuity of the surgeon will often be called upon to attain this end. The devising of the pattern and the proper placement of the transplant do not depend as much on the technic as on the art of surgery.

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CHAPTER II

THE TRANSPLANTATION OF SKIN AND OF THE CORNEA

SKIN

The first attempts at skin grafting were made centuries ago by some members of the tile-maker's caste in India. They are said to have obtained remarkable results in plastic operations for the repair of nasal defects, by the use of pedunculated flaps from the forehead or cheek. They also made successful use of free flaps, including the subcutaneous fat taken from the skin of the gluteal region after it had been beaten with wooden utensils until considerable swelling had taken place. A secret cement was employed to promote adhesion and a special healing power was ascribed to this. The use of pedicled flaps from the forehead became known as the Indian method of rhinoplasty.

The Italian method, a later development, consisted in the use of a flap of a whole thickness of skin obtained from the arm. This is now commonly known as the pedunculated or pedicled flap, and is really a free transplantation of skin in two stages. The advantage of the method is evident, the transplant receiving an ample blood supply during the process of adaptation to its new environment. The procedure was first described by Gaspar Tagliocozzi, in 1597, in a work on plastic surgery published in Venice.

Free grafting of skin appears to have been introduced early in the nineteenth century by two charlatans, the story of which is told by Baroni, the physiologist. "A woman named Gamba Curta, in order to show the efficacy of an ointment she was selling, cut a piece of skin from her thigh and after passing it around for inspection, replaced it in its original bed, and dressed the area with the ointment. The next evening the graft was so far healed that no further dressing was necessary. The second charlatan also sold an ointment described as a cure for all ills and named by him 'the ointment of the French Army.' He cut a large piece of skin, including some of the underlying muscle, from his forearm and after holding it up for the spectators to see, replaced it, and dressed the wound with his ointment. Eight days later he exhibited his arm, and the scar of the wound could scarcely be seen." These two cases suggested to Baroni a series of experiments with autografts which he made on sheep. Following this, reports of isolated successes appeared, mainly in rhinoplasties, by the use of either the Indian or the Italian method.

Three methods have been evolved for skin grafting. The first is the so-called pinch graft introduced by Reverdin in 1869. His "epidermic grafting" was practiced by placing small bits of skin on granulating surfaces. A minor modification, suggested by Ollier, consisted in the use of whole thickness of skin instead of small fragments of epidermis. The second and most widely used method is known as the Thiersch graft. Thiersch, in 1874, suggested the use of strips of skin about 1 cm. in diameter from which the subcutaneous fat had been removed. Twelve years later he modified his technic by using larger strips of epidermis. The latter is the technic that to-day bears his name. He made a significant observation upon which successful skin grafting is based: when agglutination between the transplant and the wound existed the ingrowth of vessels could be seen within eighteen hours of transplantation. Thiersch assumed that a connection developed between the vessels of the granulation tissue and those of the transplant, reforming a circulation through the vessels of the transplant. This, however, has never been satisfactorily demonstrated. The third method is the one described as whole skin grafting. In 1875, Wolfe, of Glasgow, reported a successful case of a sessile flap operation for plastic purposes. In the following year a modified technic for this type of operation was announced by Krause, who advocated the use of sessile whole thickness grafts from which the fat had been removed. This procedure now bears the name of the Wolfe-Krause method.

Homoplastic Transplantation of Skin.—Homoplastic skin grafting has a much shorter history than autoplastic grafting. Successes have been the exception, and, as a result, no widespread interest in its possibilities has been aroused. In addition there has been no great stimulus to the development of homoplastic skin grafting, for in most cases the amount of skin required is not too great to be obtained by autoplasty. Skin from dead individuals was at first employed for homoplasty. Bartens, in 1888, reported a success in a fourteen-year-old boy. He transplanted skin to cover a granulating wound of the foot, obtaining his material from a woman seventy-five years old, twenty minutes after she had died of pyemia. A similar case was reported in which the desired graft was obtained from a recently dead child. Then followed reports of a number of failures. In particular, attempts to cover scalp defects with homografts were found to be unsuccessful. It was thought that perhaps the immersion of the transplant in physiological saline solution before transplantation might make for success, but the result was usually a sloughing of the transplant. Krause, in a discussion on homografts of skin, stated that all his efforts in this field had been futile, the grafts undergoing a "non-infectious suppuration." The results of Davis' work are in striking contrast to those of most other investigators. He reported excellent results in the use of skin grafts taken from amputated limbs and from cadavers a few hours after accidental death, or with the skin of stillborn babies. In a series of forty-two experiments, he claimed 50 per cent complete successes and only 12 per cent complete failures. From his experiences, Davis felt that isodermic grafting was as satisfactory as autodermic. A careful survey of the work reported by Davis leads us to the conclusion that the data given are not sufficient to prove that homoplastic skin transplantation can be performed with any great degree of success.

In general, the results of animal experiments have varied to such an extent that precise conclusions cannot be drawn. For example, Winkler, working with amphibia and reptiles, claimed as good results with homografts as autografts, while Schoene, on the other hand, met with no appreciable success with homografts.

The question of blood relationship as a factor in successful homoplastic grafting has received little attention in the past. The results have seemed to indicate that blood relationship has a bearing on the success of homoplasty, but they have been too variable for any scientific analysis. Thiersch, in the first systematic study of this problem in man, noted that skin transplants did not succeed in individuals that were not blood relatives. His work was corroborated later by studies on animals, and the question of blood relationship appeared to play a dominant rôle even in transplantation on parabiotic animals. Schoene, working with mice and rats, reported that in his experiments homotransplantation in those not related by blood was never successful. The grafts might appear viable and fresh even as long as fourteen days after transplantation, but then a rapid degeneration would invariably set in, resulting in the desiccation and discharge of the transplant. Clinically, failures have been reported in individuals as closely related as mother and son, or daughter and father. In short, no underlying principles for success or failure in homotransplantation of skin can be drawn from the studies that have been made.

Age was found to play a rôle but not one of great significance, as successes have been reported with the use of the skin of the aged as well as of the young. There have been reports of more consistent and greater success with the skin of the stillborn than with that of adults. Experimentally, the best results have been obtained in *young* individuals of the same litter. In one experiment, the skin of a mouse fetus was successfully transplanted to the mother, whereas failure followed attempts at transfer from mother to offspring.

Many clinical observers hold a pessimistic viewpoint in regard to the use of isografts of skin. Thus Lexer, after an extensive clinical survey, found that the fate of the grafts in his cases was one of the following: (1) an acute gangrenous degeneration; (2) apparent healing followed in two or three days by noninfectious suppuration; (3) apparent healing followed later by cicatricial contraction; (4) a result similar to (3) but with slower scar tissue replacement. These findings he corroborated experimentally and careful microscopic work seemed to point to the improbability of permanent viability of homografts.

An attempt to study the comparative viability of autografts and homografts, by the use of carmine as an intravital stain, indicated some very striking differences between the two. At the end of four to six days the homografts showed a brown color while the autografts retained the rose color of the stain. Microscopically these changes were more vividly seen by differences in the arrangement and color of the carmine granules.

From the foregoing, it is evident that autografts of skin have a degree of permanency in both animal and clinical surgery whereas isografts remain in the realm of experimentation. Occasional successes with homografts of skin have been more than counterbalanced by the frequent failures. It cannot be denied, however, that some satisfactory results have been encountered. The important question, and one that may have great practical bearing in the future, is how to account for the occasional success. Has it been purely accidental or is it based on some hitherto unrecognized factor? We believe that some work done in recent years offers a key to the solution of the question, and this will therefore be discussed.

Incompatibility of the blood of donor and recipient has been considered one of the prominent causes of failure of homografts. Nevertheless, no advantage was taken of the fundamental work of von Dungern and Landsteiner, proving that there were compatible as well as incompatible blood groups. It was not until 1918 that the principle of blood grouping, as used in transfusions, was applied to skin grafting. Masson, in this year, reported that, in his cases of skin grafting, the donor and recipient had been tested for their interagglutination reactions. He stated that he utilized this in all three varieties of grafts and felt that the application of the blood-grouping principle in skin grafting played as important a part in the success of homografts as it did in the success of blood transfusion. He noted that failures occurred regularly when the donor's red blood corpuscles were agglutinated by the serum of the recipient but that in all other cases isografts were as successful as autografts. A year later there appeared a report of a short series of clinical observations on homografting of skin, based on the application of the blood-group principle. Apparently initial successes occurred independently of group compatibility but permanent "takes" were modified by blood compatibility. The point emphasized was the effect of the patient's plasma on the cells that were introduced. Autografts grew best, but isografts obtained from donors of the same blood group as the recipient, or from Group I donors (universal donors, Moss system), became permanent "takes" and grew almost if not equally as well. Isografts in which the donor and recipient were of different groups did not remain as permanent takes except when Group I skin was used or when the recipient was a member of Group IV.

In my own experience, opportunity has been afforded for observing clinical successes in homotransplantation of skin by using donors whose blood was compatible with that of the recipient. Whether viability to the degree seen in autotransplantation exists remains to be proved. Unfortunately histologic criteria have not, as yet, been obtainable. I believed that they could be derived from experimental studies, but found that the usual laboratory animals do not present the clean-cut, blood-group characteristics found in man, and, therefore, could not be used for this work.

Although histologic data are not obtainable, a case now under my observation throws considerable light on this question. An elderly diabetic woman had a granulating area on the chest wall, following amputation of the breast for carcinoma. Because of her poor general condition homografting rather than autografting of skin was decided upon. Her blood was in Group IV (universal recipient) and a donor in Group I (universal donor) proved available. He was extensively tattooed and grafts were taken from some of these tattooed areas. Although the case is too recent to refer to a final result (five months have elapsed since the grafting was done), it may be stated that several grafts appear healed in place with the tattooed markings sharply defined. A striking feature is the fact that this occurred despite a discharge of pus from an area of infected costal cartilage (see frontispiece).

In the light of the work on iso-agglutination and blood compatibility, it seems possible to account for the variations in the results of homografting. On this basis one can conceive that those who inadvertently used individuals in compatible blood groups met with success, while those who did not, failed. In this sense, blood relationship can play no important rôle, for members of a family differ from one another in the groups into which they fall. The successes reported with the use of skin from newborn infants are probably to be explained by the fact that full differentiation into blood groups is not complete at birth and the fetus and newborn may be in the class of the universal donor.

The subject of homoplastic transplantation of skin cannot be left without reference to the many remarkable studies in pigmentation that have been made. In general the transplant takes on the color of the host's skin. A few cases have been reported in which the graft has retained its original color when transplanted to an individual of a different color, as from a negro to a white person or vice versa. However, one must be cautious about accepting such reports as most of them are of very early date and are not supported by sufficient data. In view of the fact that homografting has met with such little success and that, as a rule, racial differences have been a prominent factor in failure in transplantation, it seems fair to assume that these reports have not been very accurate. Furthermore, if homoplastic skin grafts are replaced to varying degrees by scar tissue, it is evident that great care is necessary in interpreting color changes, since scar tissue in a negro is usually free from pigment, while pigmented scars are occasionally found in white individuals.

Early observations on the change in color of a transplant, so that it resembled the color of the host's skin, were corroborated by Karg, the first to study these changes histologically as well as clinically. He noticed that a white graft placed on a negro become dusky after six weeks, black stripes extended from the edges of the transplant into the white skin, and black points or spots appeared in other places. The pigment gradually increased and in ten weeks the color was as black as the surrounding skin, although the contour of the transplanted piece was still distinct. In the case of a black Thiersch graft on white skin, he found after two weeks that the edges of the graft were lighter, that the central portion faded, and in about five weeks this also became pale gray. The microscopic examination of the white skin grafted on the negro showed that the epidermis in the center was entirely free of pigment after four weeks. Granular pigment was found here and there in the cells of the epidermis, especially near the pigment cells and also in the upper layers of the cutis, particularly in the neighborhood of the vessels. These pigment granules were decidedly increased after eight weeks, and, at the end of twelve weeks the pigment was so intense that the offshoots of the pigment cells could not be made out. From these observations, Karg concluded that the pigment was brought to the colorless epidermic cells by cells of a connective tissue nature derived from the cutis, and that they represented special chromatophores.

The black skin transplanted to the white was almost entirely free of pigment in six weeks. Single cells containing pigment were found in the deeper layers. The pigment, therefore, seems to have been taken up and removed by migratory cells. It has been noticed that when a whole thickness black graft is placed on a black patient, the color returns to the layers containing the pigment in the course of time.

Experimental investigations of pigment changes have brought forth little that is conclusive and the results have been conflicting. The only phenomenon that seems to be fairly constant is that, in the few cases of successful homoplasty, it is more common to find pigmented skin take, as such, when transplanted on an unpigmented site than vice versa.

In recent years, some comparative studies have been made on pigment changes occurring in homografts and autografts. It was noted that while pigmented skin transplanted to unpigmented sites of the same animal retained its viability and that the pigment invaded the adjacent nonpigmented skin, the same did not hold true for homografts. Homografts were cast off after varying periods in the majority of cases; when they remained in place the transplanted pigmented epithelium did not invade the surrounding area but, on the other hand, gradually lost its color. Certainly the observations on pigmentation do not in any way aid in establishing the view that homografts retain their viability, as the graft eventually takes on the color of the adjacent skin and does not necessarily retain the original pigment. If any conclusion is to be drawn from the large amount of work done, it is that retention of pigmentation is usually the result of degeneration of the graft with deposition of the pigment granules in the tissues of the host.

Heteroplastic Transplantation of Skin.—Reports of success with heterografts have been very few. In the earliest attempts, frog's skin was transplanted to dogs. The graft became necrotic, infiltrated with leukocytes, and sloughed off. Studies of the fate of human skin transplanted subcutaneously in rabbits showed an initial growth for about two days. This was followed by degenerative processes, leading to complete disintegration of the transplant, in eight days. The initial growth has been accounted for on the basis that the cells of the transplant carried with them a certain amount of nourishment. When this was used up it could not be replaced by the heterogenous host. The few successes reported with heterogenous skin have either been in the early history of transplantation or have not been given in sufficient detail to enable one to determine precisely the fate of the transplant. An attempt has been made to use frog's skin on granulating wounds in man, and it was claimed that the pigment disappeared in ten days and the grafts rapidly changed in character, resembling more and more the human skin. Replacement by the the host is undoubtedly the phenomenon that occurs. The successes with pigskin, and with skin from young dogs on human beings, that have been reported, likewise lack any convincing proof.

An interesting experimental study has been made by Loeb and Addison of a number of transplantations of guinea pig skin to animals of the same and foreign species (rabbit, dog, frog, and guinea pig). These observers reach the conclusion that a typical curve of growth of the transplant was obtained in each species, and that this was directly dependent upon the phylogenetic relationship of the guinea pig to the host. However, in no instance was growth noted in heteroplastic skin grafts after a period of eight days.

The isolated successes that have been reported have been few and unconvincing. At the present time, therefore, it may be stated that the heterotransplantation of skin is worthless for all practical purposes.

The Preservation of Skin Grafts.—As early as 1873, Martin, in a classic series of experiments on the viability of preserved grafts, concluded that none of the grafts lived after one hundred and eight hours in "free air" at a temperature of 0° C. When kept in hermetically sealed tubes or in "confined air" under the same temperature conditions, the grafts could be successfully transplanted after a much longer period of preservation. By comparative studies of the viability of skin at various temperatures, the viability being indicated by the ability of the transplant to "take," he concluded that: (1) preservation in cold was favorable; (2) heat was unfavorable and resulted in shortened viability; (3) moisture hastened decomposition; (4) smaller masses lived longer than larger ones; (5) grafts were best preserved in hermetically sealed tubes at low temperatures.

Since the importance of asepsis has been recognized, many methods for the sterile preservation of skin have been advocated. Some observers have reported the successful use of grafts preserved in sterile normal saline solution for periods as long as thirty days. Comparative studies on the use of antiseptic solutions in varying dilutions have shown very clearly that their use interferes with viability and is therefore absolutely contra-indicated. Preservation in sterile ascitic fluid has been tried and grafts have been transplanted successfully after a period of thirty days' retention in this medium. Martin's studies have been substantiated in other respects as well, for growth has been obtained after a longer period of preservation in a dry chamber than in a moist one.

An elaborate method for the preservation of tissues was described by Carrel in 1912. He preserved the skin of an infant that had died during labor. The body was washed with soap, water, and ether, several hours after death. Dermo-epidermic grafts and flaps of skin were detached and washed in Ringer's solution. The grafts were then put in

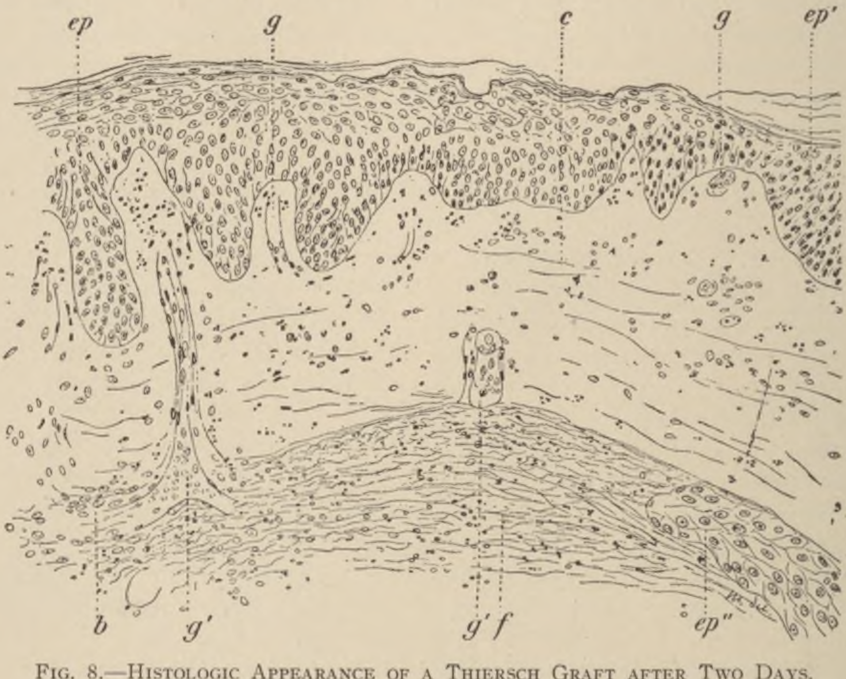

FIG. 8.—HISTOLOGIC APPEARANCE OF A THIERSCH GRAFT AFTER TWO DAYS.

ep, well-preserved epidermis. *ep'*, epidermis with shrunken nuclei. *ep''*, newly formed epithelial sprout extending under graft. *f*, zone of agglutination, fibrin with leukocytes and young connective tissue cells. *c*, cutis of the graft. The nuclei of its cells have largely degenerated and disappeared, especially in the superficial portion. In this layer are leukocytes with degenerated nuclei. *g*, old blood-vessels of the graft, showing degeneration. *g'*, newly formed blood-vessels growing into the graft from the bed, extending in part in old vascular channels (Marchand).

tubes containing warm petrolatum and the tubes deposited in the refrigerator. When the transplants were removed from the tubes of petrolatum, they were placed in Ringer's solution at body temperature before using. The grafts were used after periods varying from twenty-four hours to seven weeks. Carrel gained the impression that skin preserved for as long as two weeks grafted as well as normal skin, but that successes were not to be anticipated after that period.

In general it may be stated that an indication for the preservation of skin grafts can but rarely exist. Since successes with fresh homografts, not to mention heterografts, are unusual, this statement would hold with even greater force for preserved heterografts and homografts. Therefore, the only really practical possibility would be for preserved autografts and there is surely no occasion for such a procedure. In those rare instances in which there might be a practical indication for preservation, as in the use of homografts in individuals in compatible blood groups, the best method would seem to be the preservation in sterile normal saline solution on ice for a period not exceeding twenty-four to forty-eight hours.

Histology of Autografts of Skin.—When autotransplantation of skin has been successful the process of repair is almost identical with that

FIG. 9.—HISTOLOGIC APPEARANCE OF A THIERSCH GRAFT AFTER THREE DAYS.

ne, exfoliated necrotic epidermis on the surface. *ep*, regenerated epithelium which has sprouted under the graft at *ep'*. *b*, cystic collection of fluid and leukocytes. *c*, cutis of the graft with well-preserved elastic fibers and few cellular elements derived in part from the bed. *f*, zone of agglutination containing fibrin, connective tissue cells, and leukocytes. *a*, cells of the bed, between which elastic fibers and proliferating nuclei are seen (Marchand).

occurring in an ordinary, clean, incised wound. There first occurs an exudate of fibrin from the wound fixing the transplant in place, and the graft has been found to be slightly adherent as soon as five hours after transplantation. This fibrin layer is of variable thickness. It soon becomes infiltrated with leukocytes and fibroblasts and disappears gradually, to be replaced by a richly vascular connective tissue containing many round cells. The replacement of the fibrin layer is complete in about ten days. About fourteen days after transplantation, the granulation tissue has changed into an organized membrane.

Within a few hours after the time the graft has been applied, the leukocytes of the fibrin layer migrate into its interstices and are also to be found in the lumina of its empty blood-vessels. Most of the blood-vessels in the transplant degenerate. Sixty-two hours appear to be the earliest period in which a continuity of circulation can be noted between the host and the transplant. Garré believes that a small number of blood-vessels of the graft resume their function on the third day and are retained, but this is not proved by the evidence that is offered. By injection experiments, vessels have been demonstrated in epidermic grafts on the second and in cutis grafts on the third day. The newly built vessels arise mainly by a budding of the capillaries in the fibrin layer, and the buds not infrequently extend directly into the vessels of the graft. The success of the graft has been thought by some to be dependent on an early blood supply, but nourishment from the surrounding plasma appears to play the greater rôle.

The *epithelium* of the graft remains unchanged in the first three days. Degenerative processes then set in so that on the third and fourth day the epidermis together with the upper rete layer of the skin are lost. The middle layers degenerate and are cast off with the epidermis. Infiltration with round cells is most marked in the epithelium. The degree of infiltration is variable and seems to be dependent on the thickness of the graft—the thicker the graft the less the invasion. The degenerative processes are pronounced at an early stage, so that there is a vacuolization of the surface of the graft, and cavities appear. This is most marked in the upper layers of the epidermis. Hand in hand with the degenerative processes, regeneration goes on, and it is usually so energetic that in six to eight days the entire transplant is covered with new epithelium. The greater part of this newly built epithelium is derived from the middle and basal layers.

Degeneration extends beyond the epithelium to the *cutis* and this layer of the transplant shows pronounced degenerative phenomena. It becomes swollen, vacuoles are formed, there is a leukocytic infiltration, and the nuclei are shrunken. Only a very small number of cells, near the base of the transplant, fail to show degeneration. The entire cutis is replaced by granulation tissue which in time shows a decrease in cells and blood-vessels and an increase in fibrous tissue.

The *elastic fibers* in the graft gradually degenerate and are replaced by newly formed tissue. The latter appears to be derived, in part at least, from the preëxisting elements of the graft itself. The process of degeneration is very slow so that the fibers are unaltered for a considerable length of time. Regeneration of the elastic fibers is complete in about one and one-quarter to one and one-half years, but even then the fibers are not arranged in as orderly a pattern as in normal skin.

In short, the greater part of the transplant degenerates. The epithelium regenerates most rapidly. The subepithelial tissue degenerates and is replaced by granulation tissue that is converted into fibrous tissue derived from the host. Thus, *histologic examination establishes partial viability only, and this solely in the juxta-epithelial layer of the graft.*

The histologic changes in whole thickness grafts do not differ materially from those occurring in Thiersch grafts. In the latter, more of the epithelium is retained, whereas the processes of degeneration and regeneration are more rapid in the former. After seven days, Thiersch grafts present an almost complete replacement of epithelium; in the Wolfe-Krause flaps, one still finds degenerative masses in the epithelium. Blood-cells appear only in that portion in close proximity to the bed. Thiersch grafts may be completely injected via the vessels of the host, while whole thickness grafts can be injected only to a limited extent. The connective tissue of the Wolfe-Krause graft is replaced more gradually and, on the whole, healing is effected more rapidly in the Thiersch than in whole skin grafts.

The sweat glands near the edge of the transplant show proliferative changes and from these there develops a new growth of epithelium.

FIG. 10.—SECTION OF A THIERSCH GRAFT TWO YEARS AFTER TRANSPLANTATION.

Remains of the transplanted skin with old elastic fibers, from which apparently newly formed fibers (*t*) extend into the papillae. Scar tissue below the graft, *t*, with very numerous fine new-formed fibers (Marchand).

Glands that are more centrally placed degenerate and become infiltrated with leukocytes. The transition between the degenerating glands and those in which the epithelium remains viable and proliferates is not abrupt, so that in some places both processes go on hand in hand. The hair follicles change in about the same way. Those near the edge of the transplant show viable epithelium with little degeneration, while those more centrally placed degenerate and are infiltrated with leukocytes. For this reason a whole graft bearing hair for special cosmetic purposes cannot offer an assured outlook for success.

Skin transplanted subcutaneously behaves quite differently from skin placed on the surface. A cyst develops. In autotransplants, the cyst may persist for a long period of time or may even remain permanently. The connective tissue breaks into the cyst in a limited area around the hair follicles, the epidermal lining being otherwise normal. This tissue invades the lumen of the cyst more and more and the epidermis may disappear by a transformation into keratin. At this stage, a cyst is still present but lined and partly filled with connective tissue. In instances in which the cyst disappears it becomes gradually filled with fibrous tissue, and the end result is merely some hairs embedded in scar tissue. The danger in using skin grafts to line a closed cavity is, therefore, clear. There must be some escape to obviate cyst formation, otherwise the purpose of the transplant may be defeated.

Studies on sensation have shown that a considerable period of time elapses before a return to the normal. At first there is a sensation as of a foreign body, gradually disappearing in several months. In this period, coldness is experienced when the grafted area is touched. For some time there is a zone of hyperesthesia of the skin immediately adjacent to the graft. Tactile sensation returns first, then pain, and lastly the temperature sense. The return occurs first about the periphery of the graft, gradually extending towards the more central portions.

FIG. 11.—THE RESULT OF REVERSAL OF A SKIN GRAFT AFTER ONE YEAR. The original direction of the hair and character of the skin persists (Schoene).

Sensation over the whole graft only approximates the normal after a year to a year and a half. Even then sensation is reduced as compared with adjacent ungrafted areas of skin in many instances, although I have seen a few cases in which complete return of sensation appeared to have occurred.

A survey of the histology above given makes it clear that the transplantability of autografts of skin is absolutely established. That evidence of *permanent* viability of at least parts of autografts exists is based chiefly on clinical observation. The texture of the transplanted skin permanently resembles that of the field from which it was taken and not that of the field to which it had been transferred. Some hair not infrequently continues to grow from the transplant and here again the resemblance is to the hair at the source of the graft and not at its new situation. Such observations do not prove total viability of the graft. In fact, clinical signs of varying degrees of atrophy of transplanted skin are the rule. I have, however, observed two cases that present convincing evidence of persistence of the grafts as such, one showing apparently total preservation, the other manifestly partial viability. The latter is perhaps the more instructive of the two in demonstrating conclusively that viability was preserved in those portions of the graft nearest the sources of nutrition in the host.

The first case was that of a woman forty years old, presenting a granulating wound of the chest wall following amputation of the breast for carcinoma. In taking grafts from the thigh, I found a slightly elevated nevus, whose surface could be included in one of the grafts. This was accordingly done, cutting the graft slightly thicker than the usual Thiersch graft. The nevus was rather peripherally situated in the section of skin removed. The grafting operation was completely successful in the clinical sense. No apparent change in the appearance

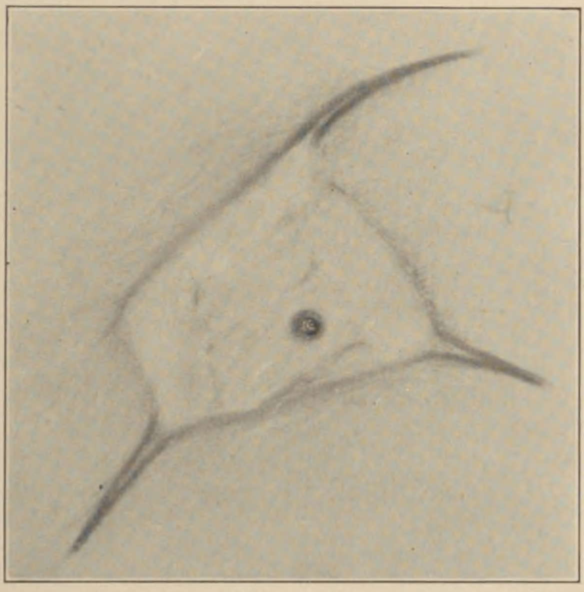

FIG. 12.—AUTOGRAFT OF SKIN FOR DEFECT FOLLOWING MASTECTOMY FOR CARCINOMA.

One of the grafts taken from the thigh bore an elevated mole. The drawing shows the persistence of the characteristics of the growth one year after transplantation. Persisting viability of the graft bearing the growth is thereby proved.

of the nevus took place in the succeeding weeks or months. It is now a year and a half since operation. The pigmentation remains localized in the transplanted growth. The appearance of the latter is identical with its original state. The surface is slightly elevated, fine cracks are seen just as they had existed a year and a half ago, but the color of the growth is somewhat darker. A discussion of the significance of apparent transplantability of a benign growth is out of place here. I would only point out that the case strikingly illustrates prolonged viability of the transplanted skin bearing the growth, the persistence of the latter being the index.

The second case was that of a young man with a large granulating area over the deltoid region following an extensive injury to the skin and soft parts. Rather thick Thiersch grafts were removed from his hairy thigh to cover the defect. The operation was successful, all the grafts taking. It is now two years since the operation. The area presents a remarkable appearance, many long dark hairs, identical with those on the thigh, being scattered through the grafted area. Upon careful inspection it is seen that the follicles from which they spring are *all* situated close to the periphery of the individual grafts and almost every graft is thus outlined by a series of hairs. For the rest, the grafted patches of skin resemble in appearance and texture the skin of the thigh. Thus the presence of the hairs establishes viability of at least the peripheral portions of the grafts, where vascularization and nutrition from the host would first exist.

General Indications for Skin Grafting.—The main purpose of skin grafting is to cover skin defects. These may be the result of operation, of injury, or of disease. The areas to be covered may be of recent origin or of long standing. In any case, grafting accelerates final healing even if only partially successful, and stimulates the growth of the epithelium from the edges of the wound. It is well known that grafting is more likely to be successful in recent wounds than in those covered by old granulation tissue. The latter condition is not a contra-indication, however, for grafts not infrequently "take," in part or wholly, under seemingly unfavorable circumstances. Skin grafting is not only the oldest but, on the whole, the most serviceable of all the varieties of tissue transplantation. I have gained the impression that it is not used freely enough in the present-day care of wounds. It is impossible to detail the innumerable conditions for which it can be employed with great advantage to the patient. By outlining some of the special indications for skin grafting, it is hoped that others will be encouraged to widen the scope of its application.

Special Indications—*Avulsion of the Scalp.*—The entire scalp may be completely torn away as a result of an accident, chiefly industrial, or it may be attached by more or less of a pedicle. Both clinical and experimental work prove that the scalp will not heal in place after having been detached. It is, therefore, useless to replace the scalp *in toto* and expect it to heal, but strips of the avulsed scalp may be successfully applied to the periosteum along the wound edges in the form of immediate, whole thickness grafts. Temporizing, by attempting to graft much of the avulsed scalp is most undesirable, however, for the best time for skin grafting in the ordinary way will have been lost. We believe that the best time for skin grafting is directly after the patient has recovered from the shock of the injury. In a case in our experience, a prompt and most gratifying result was obtained by Thiersch grafting of almost the whole denuded area the second day after the injury. This is to be compared with the prolonged and trying convalescence of patients grafted after the wound has been covered by granulations. If periosteum has been avulsed, infected areas over the cranium usually delay and not infrequently interfere with satisfactory grafting for months. Avulsion of the scalp comprises an imperative indication for skin grafting. Of all the methods that are employed, Thiersch grafting has given the best results and is, therefore, the method of choice.

Dural Defects.—Skin transplants have been tried experimentally and clinically to fill in complete defects of the skull exposing the brain. The skin is replaced by scar tissue, however, to be followed by adhesions to the brain surface. The results must be most unsatisfactory and the use of skin grafts for this purpose should be abandoned.

Depressed Scars.—For the correction of depressed scars of the forehead or face resulting in considerable deformity, a special plastic procedure has been devised. The scar is excised and fat is grafted to fill the depression. The fat implant is then covered with Thiersch grafts. The cosmetic results obtained by this method are described as very satisfactory.

Eye Surgery.—In plastic operations about the eye, both free and pedicled skin grafts have been extensively used, especially for the repair of extensive deformities following the wounds of warfare. Many remarkable results were described during the World War.

Eyebrows.—Krause first described the use of free, whole skin grafts for the replacement of eyebrows and stated that there was a regeneration of hair in the transplant. The method has not usually been successful in the hands of others; degeneration of most or all the hair follicles without subsequent regeneration was found to occur in the majority of instances. At present the best method for the replacement of eyebrows appears to be a pedicled flap, using half of the opposite eyebrow with the base of the flap at the root of the nose. The flap is then rotated into place, care being taken to prevent a torsion of the pedicle. A method that appeals more strongly to us consists in the use of a long pedicled flap taken from the scalp near the hair line.

Cicatricial Ectropion.—As much of the cicatricial portion of the lid is removed as is necessary to render the lid freely movable and to bring it into normal position without tension. The free border of the lid is spared wherever it has been preserved. The lid is placed in position and retained by suture to the opposing lid. The incision now gapes widely. As the ectropion would return if healing were to occur without filling the defect, the raw area must be covered with skin either by pedicled or free skin grafts. The latter suffices for ectropion of the upper lid. In the case of the lower lid, the cosmetic effect is not usually pleasing, as the graft is of different color from that of the surrounding skin. Plastic repair is, therefore, usually indicated. In free grafting the transplant should be from one-third to one-half larger than the exposed area in order to allow for any shrinkage that may occur.

Symblepharon.—In the severe cases a plastic operation becomes necessary. The operation consists in division of the adhesions and the use of skin grafts to prevent their recurrence. The eyelid is dissected from the globe and the cicatricial tissue is removed. A plate of lead or other material is cut and shaped to fit and an aperture is made for the cornea. The plate may be covered with paraffin. Thiersch grafts are taken from the inner aspect of the arm and placed over the edge of the plate, with their raw surfaces outward, in such a way that the denuded area on the lid and eyeball will be entirely covered with skin. With the grafts clinging to it, the plate is put in position inside the eyelids. Sutures are introduced to hold the lid margins together for a few days. The plate may be removed in five days. Permanent cure usually results from this procedure. Occasionally the grafted skin on the eyeball is visible and then the cosmetic effect is not perfectly satisfactory.

Restoration of Culdesac of the Globe.—Wolfe grafts have been used successfully in cases in which the eyeball has been lost and the culdesac has become obliterated. After the graft has been applied, it is necessary to keep an artificial eye in place until shrinkage has ceased, removing it at frequent intervals for cleaning. Skin grafts have also been used to repair smaller defects of the conjunctival sac. Mucous membrane, however, has proved to be more satisfactory for this purpose (see Chapter III).

Nose.—Skin grafting had its origin in the effort to repair nasal defects and deformities. A great many methods have been devised. In many cases the ingenuity of the surgeon is taxed to the utmost to obtain a satisfactory cosmetic result. The methods used for complete rhinoplasty fall into various groups. In the main, they involve pedicled rather than free grafts and are not strictly germane to our subject. Additional free grafting of skin is often required and, therefore, the procedures will be briefly outlined.

Indian Method.—This now consists in turning down a flap from the forehead with division of the pedicle as a second stage. The method does not prove satisfactory for the repair of a saddle-shaped nose as there is no support beneath the flap and the result is a flattened area. Several modifications, such as osteoplastic flaps, have, therefore, been devised. Perhaps the simplest is one which consists in raising a horizontal flap from the forehead and boring a transverse tunnel under its periosteum wide enough to accommodate a strip of cartilage. The eighth costal cartilage is resected, and a strip of the required length is introduced into the tunnel. About two weeks later the flap with its cartilage is turned down. The frontal wound is then covered with Thiersch grafts.

Italian Method.—In the sixteenth century, Tagliacozzi described a method of rhinoplasty that involved a pedicled flap raised from the arm. Several modifications of this method have been employed, the chief of which is based upon the addition of a free bone transplant. A piece of bone of the required size is cut from the tibia and placed under the skin of the arm. When it is well healed in place, a flap, including the bone, is fashioned on the arm and sutured to the nose. The pedicle is then divided at a later stage.

Finger Method.—James Hardie, in 1875, transplanted the fourth or little finger under the abdominal wall, raising a rectangular flap about it. This was subsequently transferred to the nose. Recently there has been a revival of interest in this operation and several modifications have been suggested. It seems, however, to have no great advantage over the other methods and, in addition, entails the loss of a finger.

The French Method.—This is based on the use of a pedicled flap from the cheek. The deformity resulting from this procedure is obviously a contra-indication to its use.

Of all the methods, the best seems to be one using cartilage as the support and skin flaps taken from a site where a visible deformity does not result. The advantage of cartilage is that changes take place in it more slowly after transplantation than in any other type of rigid tissue that can be used.

Partial rhinoplasties do not offer such great difficulties and either free or pedicled flaps may be used, depending upon the size of the defect. For the repair of the tip of the nose, the Italian method, using a pedicled flap from the inner side of the forearm just above the wrist, approximates the ideal.

Ear.—Defects of the auricle are even more difficult to correct than nasal defects. The methods employed are very similar to those used in rhinoplasty, but the results are not as satisfactory. The cavity left by a radical operation for chronic middle ear disease is sometimes grafted. Contact of the graft with the underlying tissues is maintained by means of suction with a very fine pipette that extracts the air, allowing the grafts to be held in place by atmospheric pressure.

Defects of Mucous Membranes.—Skin grafts have been used to repair mucous membrane defects, especially in the mouth. For this purpose free grafts are usually unsuccessful because infection cannot be avoided. Better results have been obtained with inverted pedicled flaps.

For cicatricial ectropion of the lip the same principles are applicable as those described in cicatrical ectropion of the eyelids. However, in cases of very extensive formation of scar tissue, as after deep burns, plastic flaps offer better results. A large U-shaped flap is cut with its base near the vermilion border to permit mobilization of the lower lip. The defect that remains is then covered with a pedicled whole skin graft taken from the arm.

Ulcers.—In chronic ulcers of the varicose variety, satisfactory results may be obtained occasionally by the use of skin grafts. It is essential that infection be adequately controlled before grafting is attempted. Ulcers with indurated and scar tissue do not graft well, and it is best to excise the scar tissue before transplantation is attempted. Thiersch grafts give the best results under these conditions. The circulation in the leg is proverbially poor in chronic ulcer of the leg and must be improved by rest and elevation of the limb before any operative procedure.

Esophagus.—Skin grafting has a prominent part in most of the methods of esophagoplasty that have been planned for the treatment of impermeable strictures of that organ. Sections of various parts of the gastro-intestinal tract—stomach, jejunum, transverse colon, greater curvature of the stomach, etc.—are mobilized or isolated according to the different methods for the purpose of replacing the obliterated portion of the esophagus. Such segments are then usually brought up under the skin of the chest wall to approach the cervical portion of the esophagus. Usually the latter cannot be reached, however, and skin grafts are then used to bridge the intervening defect. The failure of most of these methods of circumventing the strictured portion of the esophagus is not due to the skin grafting, for the latter has often been successful in plastic procedures that were otherwise unsatisfactory.

Hypospadias.—Hypospadias is treated by various types of dermoplastic operations. The formation of the new urethra is accomplished by freeing the existing portion. The resulting defect is closed by means of epithelial grafts or by flaps of skin taken from the penis or scrotum. In another method, skin is taken from the thigh to line a subcutaneous tunnel made by means of a trocar. On the whole, the present methods are not followed by satisfactory results. Epispadias offers similar problems to those encountered in the treatment of hypospadias.

Cavities in Bone.—Dermoplastic operations have been extensively used for lining bone cavities. The Reverdin or pinch grafts are very satisfactory in the smaller sterile cavities. For the larger cavities, better results are obtained with sliding grafts from the wound margins. In old bone cavities covered by thin granulation tissue, preliminary perforations through the bone surface have been suggested in order to permit new granulations to sprout through these openings.

Contra-indications to Skin Grafting.—It cannot be predicated in any given case that free grafts will succeed. One may, therefore, state that in general a pedicled flap or some type of plastic closure is preferable to a free graft, whenever such procedures can properly be carried out. In spite of the work that has been done on transplanting immunized flaps to infected wounds and the reports that have been published on successes with grafts on infected areas, infection still remains the most important contra-indication to skin grafting. Albeit true that in the presence of low grade infections a certain degree of success can be obtained, this is so unusual that it is wiser to refrain from any grafting procedure when infection exists.

The general condition of the patient must be considered, for grafts as a rule do not "take" on luetic patients or patients debilitated by a long, wasting illness such as tuberculosis. In homoplasty, syphilis or tuberculosis in the donor constitute absolute contra-indications.

Selection of the type of graft to be used in a special locality is also a great factor in the success or failure of the graft. For example, in exposed positions or in places where the graft will be subject to considerable trauma, as on the sole of the foot, thin grafts are not indicated. In these cases the whole thickness grafts are best suited for the purpose. Again, allowance must be made for some shrinkage of

Thiersch grafts. They are, therefore, undesirable about the face where deformity might ensue or where a cosmetic result is sought. Good judgment in the selection of the type of skin graft required for the special situation is one of the most essential elements in the success of the procedure, for it is evident that there are many situations in which an actual success of the wrong type of graft can be classified as a clinical failure.

Technic.—Ideal chances for successful grafting exist in a clean, recently denuded area, rather than in a granulating wound. If a situation exists in which it is felt that grafting will have to be done eventually, it is generally wise to graft at once.

Preparation of the Area for Grafting.—The wound must be free from infection before any grafting procedure is attempted. It may be sterilized by the Carrel-Dakin method, dichloramin-T, the application of various wet dressings, etc. We have found that daily exposures of wounds to sunlight not infrequently improve their condition to such an extent that grafting can be safely practiced with very little additional preparation. The state of the wound can be estimated by making daily smears from the surface and determining the number of bacteria per field in the microscopic examination. Negative cultures for bacteria are, of course, desirable but cannot always be awaited before grafting.

Katzenstein described a method of transplanting "immunized flaps" to infected fields. The antibody formation is supposed to be effected by the use of daily dressings, saturated with the pus of the wound to be treated, over the area that is to furnish the transplant. Yates has recently claimed some success with this method. Until further evidence is furnished, however, it cannot be seriously considered.

The granulations are treated in various ways at the time of grafting. Some surgeons transplant directly to the surface of the granulations providing they are clean, of healthy color, and not exuberant. The advantage of placing grafts on undisturbed granulations is that there is no pain during the preparation of the wound or application of the graft, and less time is taken. In addition, there is little likelihood of blood or serum collecting under the graft and no danger of stirring up an infection. Since granulation tissue is ultimately formed between the transplant and the host it does not seem advisable to us to remove the granulations when they are healthy, and we always graft without disturbing them. But exuberant granulations must first be reduced by appropriate measures.

On the other hand, Thiersch believed it was necessary to remove the granulations in order to transplant directly on a firm base and not to unstable granulations. Many hold this viewpoint at the present time. The granulations may be removed with a stiff brush, a knife or preferably a curette, down to the underlying base. If the skin edges of the wound are unhealthy, they too are removed, and if the surface to be grafted contains scar tissue, as much is excised as is practicable.

Antiseptics, especially powerful ones, are to be avoided. Although they destroy bacteria, the superficial layers of the wound are also damaged so that the graft is placed on devitalized tissue.

Perfect hemostasis is essential. Bleeding beneath a graft will prevent its early agglutination, an absolute essential for nutrition and the preservation of its viability. If considerable oozing from the wound occurs and is not adequately controlled at the time of operation, it is advisable to apply a compressing dry dressing and postpone the transplantation to the following day.

The skin area from which the graft is to be removed is shaved and then washed throughly with benzine, alcohol and ether. The site selected is usually the anterior and internal aspect of the thigh, but occasionally the arm and leg are used. Very hairy regions should not be chosen if the presence of hair in the grafted area will interfere with the cosmetic result.

Reverdin or Pinch Grafts.—This procedure, as ordinarily practiced, consists in transplanting fragments of skin about the size of the head of an ordinary pin. The fragment includes a little of the cutis vera. Numbers of grafts are transferred to the area to be covered and each is supposed to act as a center of growth for epithelium if it lives. The skin is held tense and the point of a needle is introduced for a depth of about ½ mm. The small cone of epidermis is then cut off beneath the needle and the graft is transferred to the wound by sliding it off the needle. Care must be taken that the edges are not rolled. The grafts are placed in rows on the wound surface. Various minor modifications of this method have been made, such as transfixing a bit of the superficial layer of the skin with a sewing needle held in an artery clamp and raising it to form a cone. A razor or sharp scalpel ablates the graft which is then transferred, on the needle, to the desired point. Since Reverdin grafts can be detached with little or no pain and can be applied to undisturbed granulations, an anesthetic is often unnecessary. This type of graft is most suitable for lining bone cavities and small granulating wounds.

Thiersch Grafts.—These are usually taken from the anterior surface or inner aspect of the thigh. The skin, moistened with normal salt solution, is held on the stretch by an assistant (special retractors are devised for this purpose) before the strips are cut. The grafts are then cut with a sharp razor or knife, with a sawing motion. The razor or knife is applied flat to the skin area near the assistant's hand. Broad and heavy knives with attached handles, razors ground on the flat (not hollow ground) or the ordinary razor blade may be used. The special knives that have been devised have no advantages over the ordinary razor.

The strip should be translucent and, if possible, of the same thickness throughout. The thickness of the graft, as originally described by Thiersch, corresponds to the cap of an ordinary blister. This usually includes, in addition to the superficial epidermis, the papillary layer as well as a portion of the reticular layer of the corium. The strips are spread over the wound just as a large microscopic section is spread on a slide. The best method of doing this is to carry the undisturbed graft on the razor blade directly to the area to be grafted. Holding the sharp edge of the blade to the wound, the end of the graft is gently drawn away with a needle or probe. As the blade is slowly pulled away parallel to the wound, the graft slips off and lies flat on the surface. If there are any little folds in the graft they can be straightened out with needles or probes after the manner of spreading sections of tissue on the slide for microscopic work. Sometimes if the graft becomes tangled on the razor blade it is well to put it in a basin of salt solution and float it back on the blade. The strips should extend about 1 cm. beyond the margin of the wound. The grafts are applied with as little space between them as possible, just enough to allow for the escape of secretions. If too far apart, secondary contraction occurs with the formation of mosaiclike scars.

Wolfe-Krause or Whole Skin Grafts.—The points insisted upon by Krause are absolute asepsis and what he terms a dry operation. By this is meant that no solutions come in contact with the area to be grafted and that hemorrhage is completely checked. Vigorous scrubbing and antiseptics are to be avoided in preparing the field for operation. The strip of skin, in the form of an elongated spindle, should be taken from the thigh or arm or from the back in children and the resulting defect closed by sutures after the edges have been undermined. If large flaps are required, the resulting wound should be closed at once with epidermal grafts. In calculating the size of the whole skin graft to be chosen, an allowance should be made of about one-third more than the size of the defect to be covered, in order to plan for elastic shrinkage in the graft.

In detaching the graft, Krause advises dissection close to the cutis so that the strip when free contains no fat. This technic has been modified by removing the skin, together with a thin layer of subcutaneous fat, spreading the reversed graft on a flat surface, and removing the fat with forceps and scissors. It has been demonstrated that flaps containing subcutaneous fat will heal in place, but, as a rule, they offer no advantages. In the parts of the face where the least contraction produces distortion, and particularly about the eyelids, it is preferable to use flaps containing a thin layer of fat, as they become softer and more movable than without fat. If any fat is to be used, the fatty layer should be of the same thickness throughout.

The flap is applied, raw surface to raw surface, is handled as little as possible, and is pressed down evenly with gauze. If the wound to be covered is not yet dry after the flap is detached, the graft should be kept folded so that its raw surfaces are in contact. Chances of injury to the flap are diminished in this way.

Krause's method has been modified by the use of a "wet technic." The graft is placed in warm sterile salt solution until required. The area to be grafted must be covered by healthy granulations, smooth and level with the surface. It is cleansed thoroughly on the day before operation without starting any bleeding, and dressed with a mild antiseptic wet dressing.

By either method the transplant usually becomes tightly agglutinated to the surface of the wound in a very short time. To aid this, the edges of the defect and the flap should be closely and accurately approximated. Sutures can, as a rule, be dispensed with, as they either exert tension or interfere with repair of the portions of the graft included in them, and always invite infection.

Dressings and Postoperative Care.—The whole thickness flaps are covered with a sterile dry gauze bandage, placed immediately over the graft to hold it snugly in place. A splint is sometimes desirable. This appears to be the best method, although wet dressings from the outset are advocated by some. After a few days, the flap appears cyanotic and its epidermis separates. If portions of the graft become necrotic, they dry under aseptic treatment and are finally discharged from the surface of the underlying granulation tissue. When the greater part of the flap is unhealthy and is yet warm for a period as long as ten days, wet dressings may be applied to hasten the separation of the necrotic areas. Immediate inflammation prevents complete healing. If, however, the flap becomes firmly attached in a few days, it withstands infection well, the development of an exudate beneath it being almost impossible. A brown pigmentation sometimes appears in spots and stripes, unevenly distributed. This probably originates from the broken down hemoglobin of the blood remaining in the flap. The graft may become somewhat irregularly shriveled after a time, probably due to the puckering by cicatricial tissue in the depths of the wound. Whole thickness grafts placed on granulations project at first above the edges of the wound, but during the process of repair they are drawn to the level of the surrounding skin.

Several types of dressings have been advocated for the Thiersch and Reverdin grafts. One method is the use of overlapping strips of rubber tissue next to the graft and, over this, wet dressings of normal salt solution. Dressings applied directly over the graft are employed by some. Others alternate wet and dry dressings. Additional methods are dressings with dry powders, ointments, or silver foil.

If moisture is desired, a satisfactory technic is the use of a cage made by fixing rings of sterile gauze to the part above and below the grafted area. Narrow strips of sterile wood are laid across these rings and a dressing is placed over them. In this manner a moist chamber exists and at the same time there is no pressure on the grafted area. Perhaps the most popular method is the use of a paraffin mesh gauze of fine consistency. This has little tendency to stick to the grafts and the perforations permit the escape of secretions.

Open-air treatment has been advocated with the belief that the rapid drying of the secretion following exposure to the air favors agglutination. This method is facilitated by the use of molded wire cages. Our own preference has been for the elimination of all dressings, other than a cage in cases where some sort of protection is indicated. We have seen the best results under such circumstances and believe that any kind of dressing next to the delicate grafts can only interfere with repair. In the exceptional cases that require dressings, paraffin mesh gauze has given satisfactory results in our hands.

If infection in the wound occurs, as many grafts as possible are saved, those having pus beneath them being removed.

The raw areas from which grafts were taken are covered with some sterile bland ointment such as boracic acid or zinc oxide, or simply with rubber sheeting. Dry dressings should not be used because of pain accompanying their removal.

In the technic of skin grafting, some methods have been advocated to increase the chances for successful "takes." The X-ray has been used to stimulate the growth of skin after transplantation, but without any manifest success. It has also been tried with the idea of facilitating "takes" in heteroplastic grafts. Because of the destructive action of X-rays on the lymphoid cells, that figure so prominently in the reaction of the host to heteroplastic transplants, it was thought that success in such grafting would be aided. The procedure has apparently been of no avail. The same statement holds for the application of electricity. In short, no method has as yet been developed to increase what may be termed the natural chances for successful skin grafting.

Anesthesia.—Grafts are usually removed under general anesthesia but other methods have been suggested. The areas may be frozen with ethyl chlorid. Thiersch grafts have been removed and transplanted successfully by this means. Any method that even temporarily interferes with the normal condition of the skin does not appeal to me, and the use of ethyl chlorid or other local anesthetics cannot be advocated. Some years ago, blocking of the external cutaneous nerve near the anterior superior spine of the ilium was suggested, since a large area of the skin of the thigh would be anesthetized thereby. We have managed to accidentally strike the nerve with the needle in some cases and have failed in others. In some cases considerable dissection was necessary before the nerve could be found. We have abandoned this hit-or-miss method, preferring general anesthesia in all cases. If general anesthesia is contra-indicated for some reason, Reverdin grafts, that can be removed painlessly, are preferable.

The Clinical Value of Skin Grafting.—It is unnecessary to summarize all the situations in which skin grafting is of value, for I have indicated the wide sphere of usefulness of the method. We have stated our impression that skin grafting is all too little used and often too long deferred at the present time. The more promptly employed the better the result. Skin grafting should not be reserved as a form of last measure to heal a chronic granulating wound, although it may often be efficacious under such circumstances. Whenever a deformity, a painful scar, an unsightly appearance, or some interference with function can be anticipated as the probable result of the ordinary healing of a wound, skin grafting should at once be thought of as a prophylactic measure to combat such sequelae. Even partially successful skin grafting is of great value for, in addition to islands of skin that remain, there is effected a stimulation to epithelization of the other parts of the wound. Finally, the economic factor in many patients with large granulating wounds, often the result of industrial accidents, deserves careful consideration. It is well known that the early stage of rapid epithelization of large surface wounds is followed by one of much slower repair. By promptly practicing skin grafting, as soon as the wound is ready for it, much time may be saved and better results often obtained.

THE CORNEA

The treatment of an eye that has lost its vision due to a clouding of the cornea has always presented a difficult problem. A French oculist, Pollier de Quensy, is said to have been the first to study the question. In 1789, he replaced a clouded cornea with a piece of ground glass, but the result was an early extrusion of the foreign body. This effort, however, awakened considerable interest in the use of transparent inert substances. The invariable failures that resulted with such procedures eventually dampened the ardor of the early investigators and it was finally realized that inert substances always acted as foreign bodies and were expelled sooner or later.

Heteroplasty was the next step in the evolution of corneal grafts. In 1818, Reisinger, after experimental researches, suggested the use of the rabbit's cornea. Many similar experiments (Power, Schweigger, and others) followed with no degree of success, and it was not until the studies of von Hippel appeared, in 1879, that anything new was contributed to the subject. He showed that the sole indication for corneal grafting was the replacement of a clouded cornea in an otherwise normal eye. Furthermore, he introduced the method of partial keratoplasty, which has since proved to be the most satisfactory operation. No advance in the clinical application of corneal transplantation resulted from the subsequent investigations with heteroplastic grafts. The occasional experimental successes led Fuchs, in 1895, to attempt the procedure clinically, but failures resulted in every instance. It is significant, however, that Fuchs noted that opacity occurred sooner after heteroplastic than after homoplastic grafts.

Although later experiments (Fick, Lieto Vollara, and others) with autotransplantation, homotransplantation and heterotransplantation did not succeed in evolving a satisfactory method for the transplantation of the cornea in human beings, some facts of scientific interest were contributed. Marchand's description of the changes that occur in a corneal graft is a classic picture of the histology of the process. He noted an early adherence of the transplant to the host by a fibrinous exudate. There followed a reaction in the graft characterized by edema, vascularization, and infiltration with leukocytes. A widespread necrosis of the cellular elements then occurred, with maceration of the ground substance, and, finally, a fibrous replacement of the entire graft. In some autoplasties, however, regenerative phenomena appeared, ultimately terminating in a transparent cornea. In the latter instances, a recession of the edema, vascularization, and infiltration soon

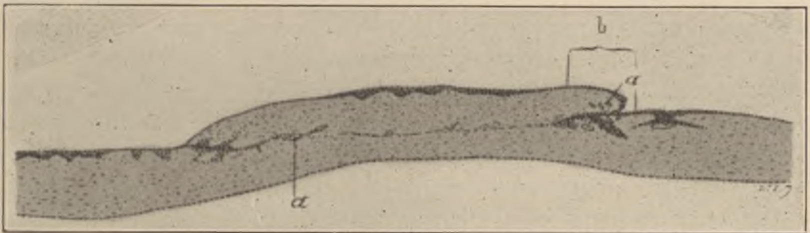

FIG. 13.—EXPERIMENTAL AUTOPLASTIC CORNEAL GRAFT AFTER TWENTY-FOUR HOURS.
This shows edema of transplant and beginning vascularization at *a*. Note the irregularity of the surface, that disappears at a later stage (Bonnefon and Lacoste).

occurred and little by little transparency in the central portions of the graft began to appear. Marchand's viewpoint, that death of the graft invariably occurred with replacement by the host, has been substantiated by more recent work.

The painstaking experiments of Bonnefon and Lacoste with autoplastic corneal grafts have established some of the factors necessary for the success of corneal transplantation. They have shown that the graft must be taken from a normal cornea. The defect to which the graft is

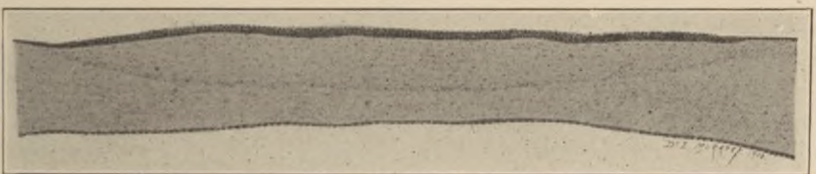

FIG. 14.—RESULT OF AN AUTOPLASTIC CORNEAL GRAFT.
At the end of five months, it shows complete regeneration of the grafted area by corneal tissue (Bonnefon and Lacoste).

transplanted should not extend beyond Descemet's membrane; in other words, the graft should rest on a bed of normal tissue, and the operation must, of course, be aseptically performed. In a series of two hundred experiments with corneal grafts, they attained from 60 to 70 per cent of successes by their procedure. Despite their interpretation of the viability of corneal grafts, a critical analysis of their work will disclose the fact that it is definitely in support of Marchand's theory.

A considerable departure from the usual experimental procedures was the work of Salzer, in 1898. On the basis of the accepted fate of the corneal graft, he thought that viable material was not necessary for transplantation. Accordingly he used grafts preserved in formalin and noted no change in the transplant for the first three months after implantation. After this period, newly laid down corneal tissue was observed around the margins of the transplant. Replacement occurred but the process was a very gradual one, characterized by an absence of vascularization of the graft. The newly formed cells appeared to be derived from the posterior surface of Descemet's membrane. At the end of seven months the greater part of the transplant was replaced, and after seventeen months the graft was no longer recognizable as such. These results were thought by Salzer to show that the preservation and fixation of the corneal graft eliminates the deleterious biochemical reactions between the host and a living transplant.

The conclusion of investigations conducted by Magitot on the preservation of a corneal graft in hemolyzed serum, was a reversion to the theory that the success of transplantation was dependent on a retention of viability. He believed that the cornea was perfectly preserved for as long a period as twelve to fourteen days when kept in hemolyzed blood serum at a temperature of 5° to 8° C.

Despite the extensive experimental work that has been done on corneal transplantation, relatively few clinical attempts have been made in this field. The occasional successes are worthy of description, since their critical analysis should furnish the basis for further studies.

The one success always referred to in the literature is the case reported by Zirm, in 1906. He replaced the clouded cornea of the eye of a man forty-five years of age with a cornea removed from a young girl. The technic employed was a total keratoplasty, a procedure that had not had experimental success. Eight months after operation the graft was still so clear that the fundus could be observed. A successful case was reported by Elschnig, who practiced partial keratoplasty. No description of the result was given other than the statement that the graft remained clear. Loehlein's operations with a similar technic resulted either in opacities, or in irregularities of the surface of the transplant with consequent astigmatism that could not be corrected by glasses.

The solitary clinical attempt at autoplasty was successful. Plange transplanted the cornea from a blind eye to the opposite eye, the cornea of which had become completely clouded from a lime burn. The site for the reception of the graft was prepared by the excision of the superficial layers of the cornea down to Descemet's membrane. An oval flap of cornea, approximately 5 by 7 mm. in size, was then removed from the blind eye and transferred to the prepared defect. The result was a partial return of vision for an unstated period of time.

In more recent years, Magitot reported a successful case of homoplasty in which the corneal graft had been previously preserved in hemolyzed blood serum for eight days. The graft was taken from the cornea of a glaucomatous eye and was transplanted to the eye of a young girl who had suffered a burn of the cornea. Two years later vision was still 5/35. Employing the same technic he transplanted the similarly preserved cornea of a fetus and noted a lasting improvement in vision from 0.5/60 to 3/50. Lastly Morax, in 1913, demonstrated a case a year after homoplastic corneal transplantation in which the vision remained good.

Technic.—Although total keratoplasty was practiced in Zirm's successful case, experimental studies have shown that partial keratoplasty is a much more satisfactory procedure. It is almost invariably necessary to resort to homoplasty in corneal transplantation. Such procedures as preservation in formalin or hemolyzed blood serum require much more trial before they can be considered. Studies in blood compatibility and their relationship to successful transplantation should offer a new angle for the study of the problem.

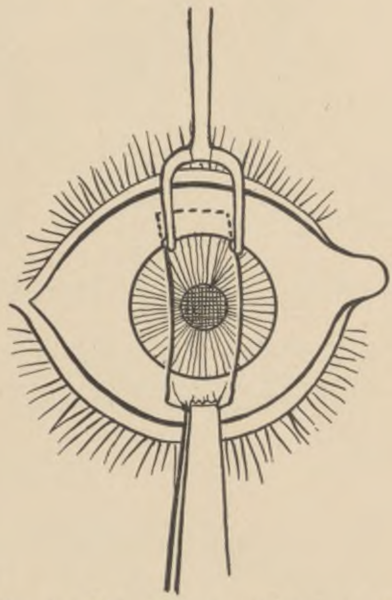

FIG. 15.—THE LOEHLEIN TECHNIC OF CORNEAL TRANSPLANTATION.

This shows procedure for outlining graft with a special knife.

The transplant is obtained from an eye with a normal cornea by excising a rectangular section that includes a small part of the conjunctiva above and below the cornea. The bed for the graft is prepared by removing a rectangular flap from the central portion of the cloudy cornea. This flap is from 5 to 6½ mm. broad and includes the entire vertical axis of the cornea. Only the superficial layers are removed down to but not including Descemet's membrane. This leaves an area of normal parenchyma for the transplant to rest upon, and does not complicate the procedure by opening the anterior chamber of the eye. The transplant is placed on the prepared defect and sutured to the conjunctiva above and below. No sutures in the cornea are necessary as prompt adhesion of the transplant to the raw surface occurs. It is important that strict aseptic precautions be maintained. In the after treatment, light should be excluded from the operated eye for at least twenty-four hours.

The Clinical Value of Corneal Transplantation.—An entirely satisfactory procedure for corneal transplantation has not, as yet, been evolved. Experimentally it has been clearly shown that the graft dies and is replaced by the host. The factors that influence a favorable substitution of the graft by transparent tissue are unknown. The early clouding that invariably occurs in the transplant does not necessarily mean failure as this recedes when a satisfactory regeneration of the graft takes place. Although in one of the few clinical successes, total keratoplasty was performed, partial keratoplasty is the only advisable method to be employed. The sole indication for corneal transplantation is the replacement of a clouded cornea obstructing vision in an otherwise normal eye (v. Hippel). Corneal transplantation is as yet in the experimental stage, but, because of its great importance, the subject deserves more attention than has been accorded it in recent years,

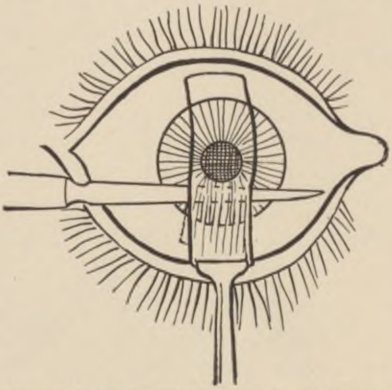

FIG. 16.—DETACHMENT OF THE GRAFT.

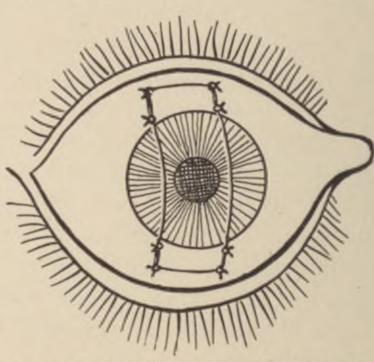

FIG. 17.—GRAFT SUTURED IN PLACE AFTER THE FIELD HAS BEEN PREPARED FOR ITS RECEPTION.

particularly from the viewpoint of homotransplantation between individuals in compatible blood groups.

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CHAPTER III

THE TRANSPLANTATION OF MUCOUS MEMBRANE, FAT, AND PERITONEUM

MUCOUS MEMBRANE

The earliest studies of mucous membrane transplantation were mainly directed toward replacing defects of the conjunctiva. After Czerny announced in 1871 that he had observed mucous membrane, taken from the uvula or from nasal polyps, heal in place and retain viability when transplanted to a granulating wound, several reports of its use in the plastic surgery of the eye appeared. Thus Stellwag, Woelfer, Becker, and others described "good results" with the use of heteroplastic grafts of mucous membrane to prevent the recurrence of symblepharon.

Some years later mucous membrane transplantation was employed in the surgery of the urethra by Woelfer. He reported two successful results with homografts placed over raw areas left after excision of strictures. The material was obtained from a case of vaginal prolapse and the technic employed was similar to the Thiersch method of skin grafting. His criteria of success were patency of the urethra for a year in one case and, in the other, pale mucous membrane, thought to be the original graft, occupying the site of the defect. Encouraged by these results, Woelfer utilized mucous membrane taken from a case of prolapse of the rectum, to replace a conjunctival defect in a blepharoplasty, and to line a skin flap that was to be utilized for a nasal plastic. In the former the result was satisfactory, but marked shrinkage of the transplant occurred in the latter. He then turned to heteroplasty and used a skin flap lined with a heterologous mucous membrane transplant for a plastic operation on the cheek. The result was satisfactory. In the light of our present knowledge it is evident that the end results were the outcome of the normal healing and regenerative processes that take place in wounds rather than the outcome of viable homografts and heterografts.

Although little experimental work has been done with mucous membrane transplantation, some interesting observations were made as long ago as 1890 by Djatschenko. His studies consisted in autografting strips of mucous membrane taken from the lip and oral cavity, to fresh conjunctival defects. The histologic changes that took place in the transplant were analogous to those described by Marchand for skin (see Chapter II). Shortly after transplantation, an exfoliation of the superficial layers of the mucous membrane was noted. The transplant became attached to the wound surface by a fibrinous exudate. From the sixth to the seventh day, the greater part of the superficial layers of epithelium was exfoliated, and there was a marked proliferation of the epithelium of the deeper layers, ultimately bringing about a complete regeneration. Newly formed capillaries were seen in the exudate as early as the second or third day, and organization of the fibrin layer into connective tissue took place. At the end of a month there was no longer any evident differentiation of the transplant from the adjacent mucous membrane.

In Raehlmann's experiments with autoplastic transplantation of mucous membrane of the lip to the eyelids, the fate of the graft was not

Fig. 18.—Mucous Membrane Transplant to Surface of Stomach, after Eight Days. The free surface of the graft faces the peritoneal cavity. The muscularis is as yet viable, but the superficial epithelium is completely necrotic save at the corners, where the omentum has become adherent (Doolin).

constant. In some experiments, the character of the transplant was maintained and a sharp line of demarcation existed between the epithelium of the graft and that of the conjunctiva. In these instances the transplant did not shrink and was recognizable years after operation by its red color. In many experiments, however, the graft was found to be shrunken, degenerated, and replaced by fibrous tissue.

The more recent experimental studies of Schmieden and Streissler with homoplastic mucous membrane transplantation do not offer any additional information. It was not until Axhausen, in 1913, undertook a careful histologic study of the free transplantation of mucous membrane that anything of further value was contributed to the subject. Since his studies comprise the most thorough work that has been done with this type of tissue transplantation, the results may be described in some detail.

The source of the material was either the gastric mucosa or the mucosa of the urinary bladder. The procedure consisted in suturing free sheets of mucous membrane to the peritoneal surface of the stomach or bladder, the epithelial surface of the graft either facing or being turned away from the viscus. Experiments with heterografts and homografts showed fibrosis, necrosis of the muscularis, and complete

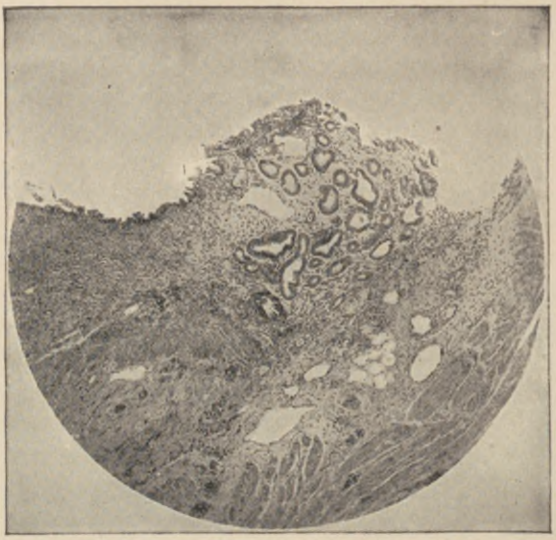

Fig. 19.—High Power Picture of Right Corner, Outlined in Fig. 18, Where Islands of Living Epithelium Still Persist.
In this section, the overgrowth of cells over the necrotic portion is well seen (Doolin).

Fig. 19a.—High Power Picture of Left Corner, Outlined in Fig. 18.
Also showing islands of living epithelium (Doolin).

disappearance of the epithelium. Only with autoplasty was any degree of success obtained. The transplant becomes converted into a cyst regardless of the direction in which the epithelial surface of the graft was faced. The cyst is tense and filled with fluid. Histologically the first changes noted were a widespread necrosis of the epithelium and muscularis. Numerous red blood-cells were present between the glandular tubules and there was a marked infiltration of the entire graft with leukocytes. In all the experiments, however, some surviving areas were observed. These were usually very small remnants of epithelium at the edges of the graft. A fibrous tissue replacement then occurred, the newly laid down tissue being ultimately lined with a single layer of cubical epithelium. The source of the newly formed epithelium was thought by Axhausen (and by Doolin, who corroborated his experiments) to be the small surviving islands of epithelium. It appears more logical to believe that the epithelium is derived from the surface with which the graft is in contact. In two of the experiments with transplanted gastric mucosa, chemical studies revealed pepsin present in one instance and free hydrochloric acid in the other. Since the period after transplantation is not mentioned, these findings are inconclusive evidence of persisting function of the grafts.

In a later series of experiments, Axhausen transplanted mucous membranes to other localities than the free abdominal cavity, namely, muscle, spleen, and liver. In every instance, the mucous membrane degenerated and was replaced by fibrous tissue with no evidence of epithelial regeneration. On the basis of these results, he maintained that the omentum, which rapidly adhered to the intra-abdominal transplant, supplied nourishment to the graft soon enough to sustain the viability of some of the epithelial cells, a feature that did not exist in other localities. These experiments surely add more weight to the impression that the epithelial regeneration is derived from a source other than the transplant, that is, from the adjacent epithelium of the host.

Technic.—The usual source of mucous membrane grafts is the lower lip. The procedure is analogous to that for Thiersch skin grafting (see Chapter II). The lower lip is everted and held under tension. Thin sheets of mucosa are detached with a sharp razor. They are placed over the previously prepared area in the same manner as Thiersch skin grafts. The site from which the graft is taken requires no special after care, and healing occurs by regeneration of the epithelium.

Clinical Application.—The clinical application of mucous membrane transplantation is obviously limited. Defects of the mucous membrane of the lips or of the oral cavity originally comprised its most important indication. However, they are usually too large to be replaced by free autografts or are much more successfully treated either by pedicled flaps of mucous membrane from the cheek, or by pedicled skin flaps, depending on the location of the defect. In some difficult harelip operations, satisfactory results are said to have been obtained by free mucous membrane grafts; this may be considered the only indication for mucous membrane grafting in or about the mouth at the present time.

One of the earliest uses of mucous membrane transplantation was for the *replacement of conjunctival defects*. Wolfe, in 1872, was the first to attempt this procedure, employing grafts of rabbit's mucous membrane. In the following year Stellwag tried heterografts as well as homografts from the mouth and vagina, but did not obtain satisfactory results. Panas used mucous membrane grafts from a dog for the same purpose but fared no better. Mucous membrane transplants were then employed in blepharoplasty to replace the conjunctiva on the inner side of a plastic flap made for the restoration of an eyelid. For this purpose, Vincentiis introduced a two-stage pedicled flap operation. The first stage consisted in freeing the pedicled flap and transplanting sheets of mucous membrane to its inner surface. Eight days were allowed for the transplant to become attached, after which the operation was completed. Because of the obvious disadvantages in such a procedure, Axenfeld's modification was a distinct advance. He first fastened the

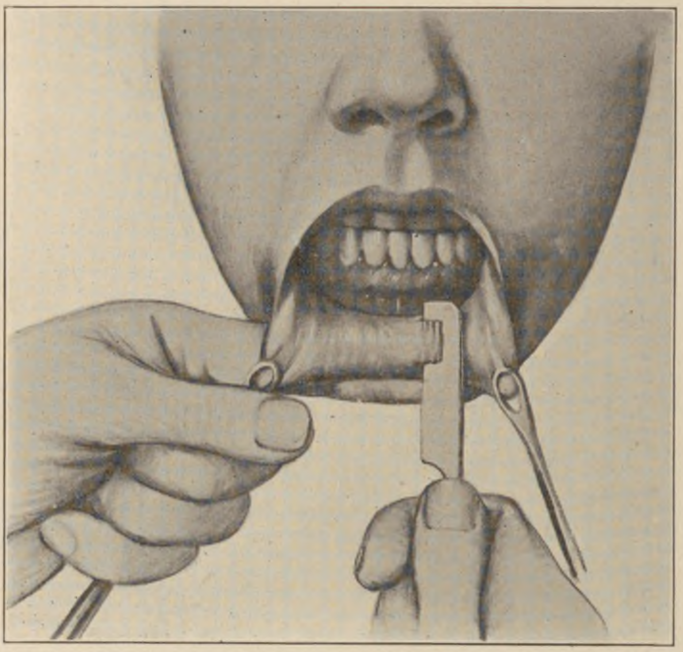

Fig. 20.—Technic of Detachment of a Mucous Membrane Graft from the Lower Lip.

grafts to the edge of the conjunctival defect and then to the pedicled skin flap, making a one-stage operation possible. This method yielded satisfactory results.

Uhthoff reported a case in which he used a temporal skin flap to replace a lower lid resected for carcinoma. The edges of the graft became adherent to the eyeball and a secondary operation had to be performed for the restoration of the lower conjunctival sac. The scar tissue was excised and the freshened surface of the new lower lid was lined with mucous membrane grafts. The result was satisfactory as noted five months later, for the sac was no longer obliterated. The sac was, however, somewhat smaller than immediately after operation because a shrinkage of the transplant had occurred.

Mucous membrane is one of the many tissues advocated for the restoration of a conjunctival sac destroyed with the loss of an eye. The early reports were rather pessimistic because of shrinkage or extrusion of the graft due to the irritation of the artificial eye. In recent years, however, the method has been accepted as being of considerable clinical value. Strips of mucous membrane are placed on a shaped metal plate or on the appropriate surface of a glass eye that is covered with wax in order to permit the adhesion of the grafts. The epithelial surface of the graft faces the prosthesis. Ten days are allowed for the grafts to become adherent to the prepared wound. The wax is then melted away with peroxid of hydrogen and the eye or plate removed. If grafts that are large enough to compensate for subsequent shrinkage are taken, the results are usually excellent.

Numerous injuries of and about the eye that were treated during the World War gave ample opportunity for the extensive use of mucous membrane transplantation in the cosmetic surgery that was necessary. For restoration of the conjunctival sac, in order to make the wearing of an artificial eye possible, the transplantation of mucous membrane has proven to be at least as good as any of the other procedures that have been advocated.

An attempt made by Lexer to reconstruct the bladder by the use of mucous membrane grafts, in a case of extrophy, resulted in failure. Since Woelfler's early homoplastic experiments with mucous membrane transplantation for defects of the urethral mucosa, the procedure has been attempted in a few instances. Lexer reported a case of traumatic stricture of the urethra in which he successfully autografted the mucosa of the appendix into the gap after excision of the stricture. Such a procedure is manifestly not to be seriously considered. The methods of repair after excision of urethral strictures are discussed in Chapter VII in which it is shown that vein grafts offer the best results in those unusual instances in which any form of free tissue transplantation is indicated.

The various operative procedures that have been advocated for the treatment of hypospadias will not be discussed. One commonly practiced operation involves the formation of a new canal by tunneling through the penis. It has always been difficult to keep this newly formed canal open. Lexer tried an autoplastic graft of mucous membrane with submucosa of the appendix for the purpose, and reported a good result. In the hands of Streissler, von Angerer, and Weitz, this procedure for replacing urethral defects resulted in failure. Axhausen recently had the opportunity to make histologic studies of the transplant in two cases treated in this manner and found that the appendicular graft quickly degenerated and disappeared. It is evident, therefore, that the procedure is not worthy of clinical consideration.

In a few cases of penoscrotal hypospadias, von Schmieden homografted ureteral tissue to form a new urethra, but his results were either partial failures or the patients were not under observation long enough to judge of the outcome. Bladder mucous membrane has been used by Eisendrath with similar uncertain results.

From our knowledge of the difficulties of free transplantation in the presence of infection, it is evident that the success of any graft in the urethra is problematical. The chances for infection exist whether or not the urinary flow is diverted by a suprapubic cystotomy or external urethrotomy. The best results in the treatment of hypospadias have been obtained with pedicled flap operations.

Clinical Value.—Free mucous membrane transplants share the usual fate of other free grafts. Degeneration with fibrous tissue replacement occurs. Epithelization from the adjacent surfaces takes place in those regions in which the method is properly applicable. Although mucous membrane transplants have been employed for a variety of purposes, their use is of proven value only in a limited field in eye surgery.

FAT

Fat grafting would probably have remained a very much neglected phase of tissue transplantation had it not been for the interest awakened in the subject by the work of Lexer and of his associates. Up to the time that Lexer undertook a systematic study of its clinical application in the treatment of a variety of surgical conditions, only isolated reports of fat grafting had appeared. The evolution of the subject can be briefly reviewed.

Neuber is accredited with making the first attempt at fat transplantation. In 1893, he reported the successful use of small free grafts of fat in cosmetic operations about the orbit. He laid great stress on the use of small grafts for, in his experiments, attempts to use large fat grafts always resulted in failure. He also reported experiments with fat implants to fill bone cavities, but only to condemn their use, as the transplants were expelled in every instance.

Three years later, Silex claimed good cosmetic results following the use of fat transplants in the treatment of depressed scars about the orbit. His method consisted in loosening the scar from the bone to which it was adherent and grafting fat between the cicatrix and the bone. In spite of shrinkage of the graft that followed its implantation, the end results were satisfactory.

Verdarme followed up the pioneer work of Silex and Neuber and, in 1909, reported a ten years' experience with fat transplantation in eye surgery. The types of conditions in which he employed fat implantation were depressed scars about the orbit, defects of the frontal bone and deformities of the orbital cavity after enucleation of the eye. Satisfactory results were generally obtained but, because of a considerable shrinkage of the fat graft, Verdarme advocated the use of larger transplants of fat than appear necessary to fill defects.

In the year in which Silex's report appeared (1896), Czerny presented his celebrated case of autotransplantation of a large lipoma to replace a breast resected for chronic cystic mastitis. There persisted a well-formed mass, slightly smaller and firmer than the normal breast, and no increase in the size of the lipoma occurred. Stimulated by Czerny's success, Bier implanted a lipoma in the cheek to reëstablish the normal contour of the face in a case of facial hemiatrophy.

Neuber's studies in the filling of bone cavities led Protherat to further experiments with fat for the treatment of the condition, and he expressed great enthusiasm over the results that were obtained. On the other hand, Tuffier, Morestin, and others could not corroborate his results and were pessimistic concerning the value of the transplantation of fat in bone cavities. In recent years, however, the work of Makkas, Rehn, Hess, and others have definitely established the procedure as one of considerable clinical value.

During the period in which the operative treatment of ankylosis of joints was the subject of careful investigation, Chaput, Roepke, and Lexer independently published satisfactory results with the use of fat grafts in its treatment. Fat was employed after resection of the ankylosed joint in order to prevent a recurrence of bony fixation.

Grafts of veins, fascia, and peritoneum had been employed unsuccessfully around nerve sutures to prevent the occurrence of adhesions to the surrounding tissues. Rehn, Eden, and others, after considerable experimental work in this field, concluded that fat transplantation was the most satisfactory procedure for this purpose. Similarly Lotheisen and Biesalski employed fat about tendon sutures to prevent adhesions.

Fat transplantation has been used in brain surgery in recent years. von Bramann, Rehn, and others employ fat grafts to compensate for the defect left in the brain by the removal of a tumor, but no reports of end results have been made. Attempts have been made to treat traumatic epilepsy by separating the brain surface from dural and and arachnopial adhesions and inserting a fat implant to prevent their recurrence. The results do not give the impression that this procedure has been of any benefit.

Although isolated reports of the use of fat as a hemostatic agent had appeared, it was not until Loewy reported his experimental and clinical results in 1903, that the procedure attracted any attention. Since that time, however, it has been extensively employed, especially to check bleeding from parenchymatous organs.

Tuffier initiated fat transplantation in lung surgery, and he also introduced the procedure in the treatment of pulmonary tuberculosis, using fat grafts extrapleurally for the compression of the diseased lung. This application of fat transplantation has not had an extensive clinical trial, apparently because of the reluctance of surgeons to employ operative procedures in the treatment of pulmonary tuberculosis. In Tuffier's hands, however, brilliant results have been obtained. Fat has also been used for the closure of bronchial fistulae but, because of the infection that is almost certain to occur and the probability of extrusion of the graft, the method can only rarely be counted upon to yield the desired result.

Fatty tissue in the form of either free or pedunculated omental grafts has been widely employed in intra-abdominal surgery. Senn is accredited with being the first to employ omental grafts, establishing their usefulness in gastro-intestinal surgery. Since his time, considerable experimental and clinical work has shown that omental grafts are of unquestioned value in protecting doubtful suture lines, in aiding the operative repair of perforations of the viscera, and for hemostasis.

The transplantation of fat has been established as a valuable aid in genito-urinary as well as in intra-abdominal surgery. Its use permits suturing of parenchymatous organs by preventing the sutures from cutting through and this has proved to be one of its important applications. In the repair of injuries to solid viscera, the fat graft serves the combined purpose of arresting bleeding and aiding suture.

It was during the World War, however, that the transplantation of fat found its most widespread application. Fat grafts played a very important rôle in the plastic surgery necessitated by the many disfiguring wounds that presented themselves for treatment.

Histologic Changes in Fat Grafts.—The ultimate fate of a fat graft is dependent to some extent on the locality to which it is transplanted and the function it is called upon to perform. The fat may be replaced by fibrous tissue or the end result may be a regeneration of fat.

For the first two or three months the histologic picture is dominated by degenerative phenomena. Some of the fat cells show an increase in protoplasm while others undergo a serous form of atrophy. A coalescence of the degenerating fat cells leads to the formation of large cysts, some of which are multilocular. Small areas of necrosis are scattered here and there in the central parts of the transplant. Fat globules freed by the breaking up of cells are partly absorbed and partly taken up by wandering cells. The graft becomes infiltrated with round cells. Many of the empty fat cells become lined with cells characterized by the German writers as *Wucherungzelle*. These are large cells with faintly staining protoplasm and occupied by vacuoles. They are also scattered throughout the connective tissue septa of the graft. The septa increase greatly in size and the entire transplant becomes surrounded by connective tissue. The latter becomes loosened and distorted by a marked cellular infiltration.

In the second month evidences of regeneration become manifest. The fat cysts are now occupied by wandering cells and *Wucherungzelle*. Wandering cells undergo characteristic changes into embryonal fat cells, appearing as nests in the connective tissue septa and in some of the fat cysts. The cysts at this stage are surrounded by wandering cells and fibrous tissue. The embryonal fat cells are then gradually converted into adult fat tissue.

The transplant becomes adherent to the adjacent tissues by broad bands of connective tissue. There is a loosely bound connective tissue envelope about the implant, acting as a delicate surrounding membrane. Finally, a considerable shrinkage of the entire mass occurs, apparently due to a contraction of this fibrous envelope.

At the end of five months the evidences of degeneration have almost all disappeared and the transplant has the appearance of normal fat tissue. The ultimate fate of a fat transplant, however, may be quite different. The same degenerative phenomena occur but the end result is a loose, cellular, fibrous tissue. Under some circumstances the entire graft becomes permeated by connective tissue so that ultimately it has

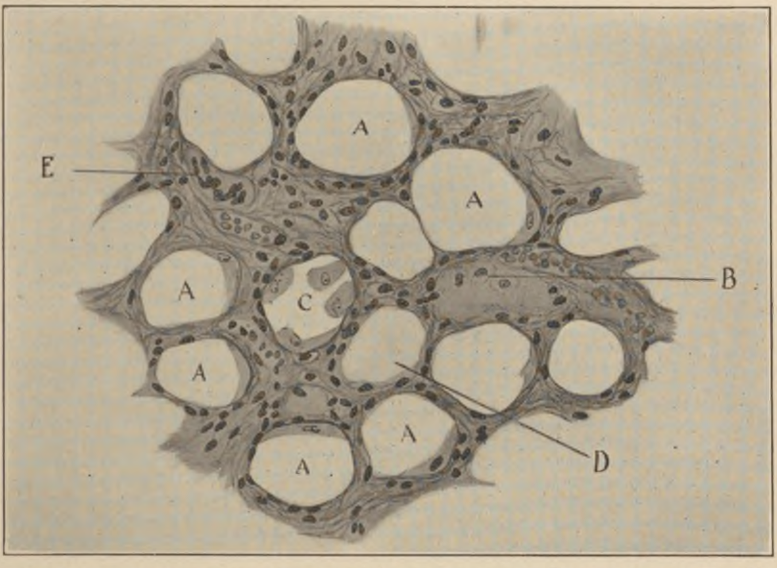

FIG. 21.—SEMIDIAGRAMMATIC SKETCH OF THE APPEARANCE OF A HOMOGRAFT OF FAT EIGHT DAYS AFTER TRANSPLANTATION.

A, fat cells with increased protoplasm. *B*, *D*, serous atrophy of fat cells. *C*, fat cell containing large endotheliumlike cells. *E*, giant cell.

the macroscopic appearance of a light, edematous, gelatinous connective tissue. The older the transplant, the richer it is in blood supply. In bone cavities, a thin layer of compact bone is formed between the surrounding spongiosa and a fat transplant. There is usually a sharp line of demarcation between the newly formed connective tissue and the newly formed bone. The factors that determine whether a fat transplant will be replaced by fibrous tissue or by newly formed fat are as yet unknown. Fat grafts may have either fate when transplanted to identical localities and under similar circumstances. The changes that occur in homotransplants closely resemble those that have been described in autotransplants, but the degenerative phenomena are more marked and rapid, and regeneration is a much slower process. Homotransplants are not infrequently expelled even in the absence of suppuration.

Summarizing, it may be said that transplanted fat undergoes practically the same changes as transplanted bone. The fat transplant dies and is replaced either by fibrous tissue or by newly formed fat, depending on undetermined factors. The evidence is in favor of the regenerated fat being of metaplastic origin despite the fact that most investigators maintain that a small part of the transplant survives and that regeneration is derived from this source. When one takes into

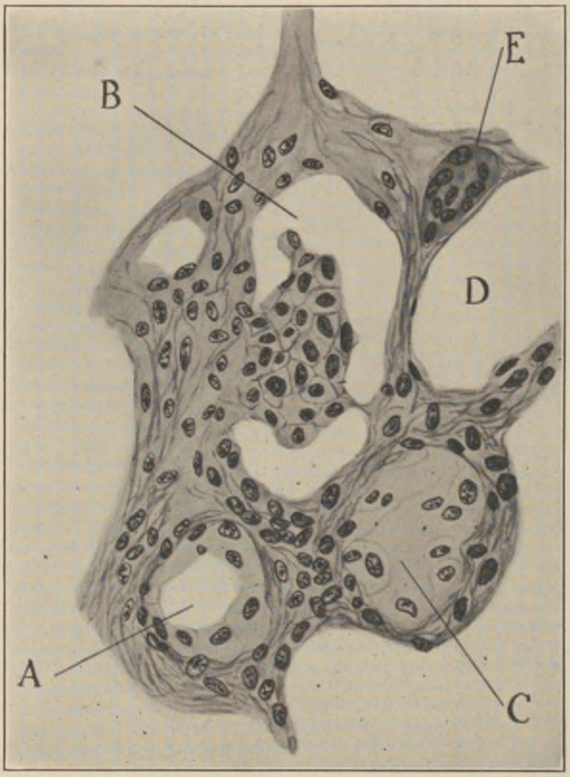

FIG. 22.—SEMIDIAGRAMMATIC SKETCH OF THE APPEARANCE EIGHT WEEKS AFTER HOMO TRANSPLANTATION OF FAT.

A, fat cell containing endotheliumlike cells. *B*, fat cyst containing a cluster of young fat cells. *C*, fat cyst in another stage. *D*, fat cyst with a wall of fibroblasts. *E*, giant cell.

consideration the massive degeneration that occurs directly after transplantation the latter view is not tenable. There must be some proof that a part of the graft remains viable at some stage and that regeneration begins in or about such an area. This evidence has not as yet been presented.

Fat Transplantation in Clinical Surgery—*Plastic Surgery of the Face.*—The transplantation of fat has one of its most important applications in the plastic surgery of the face. Depressed adherent scars of the face, especially over the forehead, malar bone, or around the orbit cause considerable disfigurement. Gratifying cosmetic results are obtained with fat transplantation under such circumstances. The scar is freed from the underlying bone and a fat implant is inserted between the scar tissue and the bone to fill in the depression. Allowance should be made for the shrinkage of the graft that occurs; larger grafts than seems necessary to fill the defect should therefore be used. Fat transplants may also be used in the cheek to restore the normal contour in such conditions as hemi-atrophy of the face. In rhinoplasty, fat transplants can improve the shape of deformed alae, and replace or correct the shape of the tip of the nose. For saddle-nose, however, its use is distinctly contra-indicated, for the graft does not offer the necessary support, and the nose will be found sunken at the site of the transplant within a short period of time. In war surgery the transplantation of fat was extensively used both in primary and secondary plastic facial operations with remarkable successes in many cases.

Eye Surgery.—Since the time of Barraquez (1901) and Barthels (1908), ophthalmologists have used fat transplants for the support of an artificial eye or to fill out the orbital cavity after enucleation of the eyeball. This procedure has largely replaced the older methods that involved the use of foreign bodies for the purpose. The entire orbital cavity or more commonly the space bounded by Tenon's capsule is filled with the fat graft. Although good results have been obtained with this procedure, complications such as necrosis or marked shrinkage of the graft not infrequently occur. Fat transplants have been used to repair wounds of the upper eyelid that would otherwise have healed with marked retraction of the lid. They have proved useful for building up the stump of an eye. In short, fat transplants have yielded very satisfactory results in eye surgery and have been of great value in the plastic work around the eye.

Deformities of the Breast.—The only tissue transplant that can be used to replace defects of the breast is fat. Since the success of Czerny with the transplantation of a lipoma for the purpose, several other satisfactory results with ordinary fat grafts have been reported. Fat transplants are indicated to fill a defect caused by the removal of a benign tumor or cyst, when the nipple remains intact. Such a procedure, however, as the transplantation of fat to replace a breast removed by a radical operation is not feasible. Fat transplants do remarkably well in the breast, only slight shrinkage occurring even over long periods of time. Girard and Lexer have reported gratfying results with mastopexy for mastoptosis. In these cases the upper part of the breast was dissected free from the chest wall and transplanted to the pectoral fascia.

Bone Cavities.—The early attempts to obliterate bone cavities with fat implants were almost invariably failures. This was probably due to the fact that the presence of infection was not taken into account. Chaput had the opportunity of observing a fat implant eight years after it had been placed in a bone cavity and found firm connective tissue in its place. Makkas, in his experimental work, demonstrated that large fat implants healed satisfactorily in place, when implanted into bone cavities. His experiments, however, were not carried beyond three months, and the ultimate fate of the grafts is not known. In some cases he found fat tissue persisting, while in others there was a complete fibrous replacement. Replacement of a transplant by bone is an uncertain and a very slow process. It depends on various factors. For example, in cavities that are not the result of infection, such as those left by the removal of a cyst or the excision of a tumor, the fat implant is more apt to be replaced by bone than in cavities following osteomyelitis.

Mosetig-Moorhof paste has been extensively used in bone cavities, but a fat implant accomplishes equally well the purpose of the paste, is not a foreign substance, and is nonirritating. Lexer and many others have succeeded in closing very large bone defects with fat.

It is essential to have absolute sterility before attempting to transplant fat into a bone cavity. Although a few cases have been reported in which the transplant was not extruded in the presence of a slight infection, a fistula usually appeared subsequently, persisting for many months. The cavity in which the transplant is laid should be dry, and too much dependence should not be placed on the hemostatic action of the fat. A blood-clot will prevent early adhesion of the graft to its bed, thus interfering with the reparative processes in addition to offering a favorable nidus for infection.

Fat transplantation accomplishes the obliteration of bone cavities better than any other known procedure. The only other tissue that serves this purpose as well as fat is muscle, but it is of limited availability and, therefore, can be used only for small defects.

Obliteration of Dead Spaces.—Fat may be employed for the filling of large postoperative tissue defects. It has been used to obliterate the dead space between the surface of the brain and the skull after craniocerebral wounds.

In the chest cavity the use of fat transplantation was introduced by Tuffier to establish a permanent collapse of tuberculous cavities in the upper lobe. The procedure consists in freeing the parietal pleura from the inner surface of the chest wall over the diseased area and the extrapleural implantation of a large fat graft. This has yielded brilliant results in some cases. The method has also been tried in lung gangrene, lung abscess, and bronchiectasis, but since the value of collapse of the lung in these conditions is very doubtful and the probability of infection great, fat transplantation appears to be distinctly contra-indicated for such purposes. Fat grafts have been used to close bronchial fistulae, but infection with extrusion of the graft is likely to occur. A dead space left by an old empyema cavity may be so filled but, again, infection is very apt to be present and the procedure cannot be considered a safe one. It is better to resort to operations that have for their purpose mobilization of the lung or collapse of the chest wall. In gunshot wounds of the lung, the transplantation of fat has often been of value as a cover for the raw areas in the damaged lung and an aid in hemostasis.

A very satisfactory result in a case of tracheal distortion by scar tissue is described by Eden. The scar tissue was excised and fat implanted into the resulting defect. In a remarkable case reported by Kollischer, the fat graft was placed, for hemostatic purposes, into the bed left by removal of the prostate. The transplant healed in place in spite of the fact that it was constantly bathed in urine.

The Prevention of Adhesions.—Fat transplantation has been extensively used to obviate the formation of adhesions. Adhesions do form between the transplant and its surroundings, but these are thought by some to be less dense than those that occur under ordinary circumstances. Lexer maintained that this was verified by his experiences in tenolysis, but he found that, while a transplant might be firmly adherent to the enveloping tissues, the tendon may move freely within it.

Fig. 23.—Semidiagrammatic Representation of Autotransplant of Fat about a Nerve after Six Months.

This shows attachment of graft to nerve by adherent fibrous tissue.

Rehn and Eden have conducted extensive experimentation in the use of fat in both tenolysis and neurolysis. Several months after transplantation, they found that there was a considerable regression of degeneration of the graft and that the connective tissue adhesions were richly cellular. In six to eight months, there was only a loose, fibrous enveloping layer and after a year the fat appeared normal except for thickened connective tissue septa. There existed by this time a connective tissue union with the epineurium or the tendon sheath. Lexer had the opportunity of seeing a fat transplant four years after it was implanted about a nerve suture and found adult fat present. On the other hand, several investigators in the same field have been unable to corroborate Rehn and Eden's work. In their experience the fat was replaced by a dense fibrous tissue.

The procedure for neurolysis or tenolysis, advocated by Lexer in cases in which the tendon or nerve is bound down by scar tissue, is to resect the scar tissue and liberate the nerve or tendon, and then surround it with a fat transplant. The results in a large series of cases are described as uniformly good.

It is our impression that early motion is the best prophylactic measure against the formation of adhesions about tendons after operation. That early mobilization usually suffices has been adequately demonstrated. As indicated in the discussion on the use of fascia for enveloping nerves (see Chapter IV), the transplant, whether fat or fascia, exists in the form of a mass of tissue about the sutured nerve. This means a source of irritation that might not otherwise exist, and the probability of extensive adhesions to the nerve. Under ordinary circumstances, adhesions about a nerve anastomosis are few and tenuous, and the prospect of their ultimate disappearance is good, but the presence of an enveloping fat, fascial, or other tissue transplant renders such an outcome highly improbable. In spite of reported successes in neurolysis and tenolysis, their use for such purposes cannot be advocated. The same may be said of the use of fat to bridge tendon defects, for it is quite evident that fascia serves this purpose much more efficiently.

Vascular Surgery.—Free fat grafts have been used for reinforcement purpose, hemostatic and protective, the latter as the result of early adhesion at the site of anastomosis. This use of fat may occasionally prove of value, but ordinarily vascular repair followed by considerable oozing will probably be unsuccessful because of intravascular thrombosis. In principle, therefore, adequate control of bleeding should be obtained by properly employed methods of vascular suture and, for purposes of reinforcement of anastomoses, fascial transplants will be found more effective (see Chapter IV).

Intra-abdominal Surgery.—In this field, fat transplants, either free or pedicled, have been of considerable value. The source of the transplant is usually the omentum. The first use made of an omental graft in intra-abdominal surgery was to effect the closure of a perforation of the stomach (Senn). Since omentum ordinarily becomes adherent to injured or infected areas, its use in protecting doubtful gastric or intestinal suture lines is logical and the free or pedicled omental flap is now universally employed and has proved a boon in many cases that present difficult problems. In operations on parenchymatous organs, there is a decided tendency for sutures to cut through. Fat interposed between the organ and the suture forms an excellent support for the latter and is, besides, of considerable value because of its hemostatic action. A comparison of the advantages of fat and fascia in operations on the solid viscera is made in Chapter IV.

Genito-urinary Surgery.—Fat transplantation has been attempted in the urethra after the excision of a stricture, but infection with extrusion of the graft usually followed. The reinforcement of a suture of the bladder wall with fat has been accomplished, but a graft is not ordinarily required, as adequate closure can usually be obtained. In the surgery of the kidney, on the other hand, fat grafts are of considerable value, the fat being secured from the lumbar wound. As an aid to hemostasis, it should prove most useful in cases in which the kidney was decapsulated at a previous operation, and for reinforcement after pyelotomy and suture.

Brain Surgery.—Although fat has been used to fill the defect left by the removal of a brain tumor, it and all other types of graft are contraindicated for this purpose, since the dead space is, sooner or later, obliterated by intracerebral pressure. Its use in the repair of dural defects is not nearly as satisfactory as is that of fascia. The use of fat implants in the operative treatment of traumatic epilepsy was proposed by Rehn. Epileptic seizures have been attributed to the fibrous changes that occur in the arachnopia and to the resulting adhesions between the brain and meninges. After excision of the scar tissue and separation of the adhesions, fat is implanted to prevent their recurrence. A critical analysis of the results reported with this procedure shows that failure to relieve the epileptic seizures is the rule. In brain injuries in which the ventricles have been opened, the transplantation of fat has been effectively used for occlusion, according to several reports of successful results. In this procedure a fat plug is inserted into the defect caused by the injury and the dura is closed over it. I believe, however, that the procedure is not based on logical grounds. Simple or plastic closure of the dura sufficed to check the escape of ventricular fluid in all the cases that have come under my observation.

During the World War fat grafts were used for filling defects and for hemostasis in craniocerebral wounds and, according to the reports, the results have been satisfactory. There is no question of the grafts having been retained, but whether or not the procedure is a desirable one remains undetermined. *A priori,* the implantation of any tissue into the brain substance inevitably involves fibrosis, and this cannot be innocuous. Future reports will be necessary in order to estimate the ultimate result of fat transplants into brain defects. It may be said in passing that a properly conducted operation for craniocerebral wounds should rarely if ever leave a dead space behind. The indication for any type of implant should, therefore, seldom arise.

Arthroplasty.—Fat transplantation has been perhaps more widely employed in the operative treatment of ankylosis of joints than for any other purposes. When the ends of the bones have been separated either free or pedicled fat grafts are interposed to prevent their reunion and to aid in the formation of a new joint.

Considerable attention has been devoted to the histological changes that take place in a fat graft that is used for this purpose. The usual processes of degeneration are noted, but those of regeneration are somewhat modified. Different portions of the graft undergo different fates, depending, apparently, on "functional stimulation." Where the transplant is free and not subjected to pressure, it is replaced by adult fat. Wherever it is subjected to pressure, as between the bone ends, a connective tissue layer develops. The part of the connective tissue layer that becomes adherent to the bone end may be converted into cartilage while the free surface of the altered graft develops an endothelial-like sheath. Where pressure is only slight, as toward the periphery of the joint, connective tissue containing islands of fat is found.

Lexer, Murphy, and others have reported excellent results with the use of fat implants, either free or pedicled, to prevent a recurrence of ankylosis, but it is very difficult, in most instances, to determine whether credit for the success of the operations should be given the transplant, or to the early mobilization that was practiced. The histologic pictures described after fat transplantation have also been seen when no interposing tissue has been used. Consideration must also be given to the fact that the introduction of any free graft into a joint is undesirable in principle. Changes in a transplant may lead directly to an unfavorable result so that an otherwise satisfactory operation can be seriously compromised thereby. Therefore, in principle, a free graft is rarely advisable in the operative treatment of ankylosis.

In spite of the widespread use of fat transplantation, and in spite of the many unquestionable successes reported, we believe that the most important factor in the treatment of this condition is early and persistent mobilization after operation. The best evidence in support of this view is the fact that satisfactory results have often been obtained by arthroplasty without the interposition of any of the substances that have been advocated.

Hemostasis.—The hemostatic action of fat is now well known. Subcutaneous fat or omental grafts are of value in controlling bleeding from the parenchymatous organs. Although fat transplants had been used for this purpose since Jobert's time (1823), it was not until Loewy's work appeared that the procedure was popularized.

The rapid cessation of bleeding after the application of fat to a bleeding surface depends upon two attributes. The first is its richness in thrombokinase, the liberation of which greatly accelerates coagulation time. Secondly, its rapid adherence to a raw surface, by which it seals the bleeding capillaries. Even bleeding from small arteries and veins may occasionally be checked with fat grafts. In such organs as the liver, the spleen, the kidney, and the brain, the control of oozing by ordinary measures may be difficult and the fat graft is of very great value in such circumstances. As an example the case reported by Stuckey may be mentioned in which venous oozing from the bed of the liver followed a cholecystectomy and was promptly checked by a fat implant.

Fat is easily obtainable for hemostatic purposes and is, therefore, the most frequently applied of the tissue hemostatics. Some writers have maintained that muscle is more effective for the purpose. There can be no question that muscle grafts act as well as fat grafts but no clear evidence has as yet been adduced to prove that muscle tissue is a more powerful hemostatic agent.

The only absolute *contra-indication* to the transplantation of fat is infection. Under no circumstances should it be employed in the presence of any gross infection, for not only may extrusion of the graft occur, but persistent fistulae may result if the transplant is not expelled. Fat grafting is an undesirable procedure in any situation in which later replacement phenomena may lead to fibrosis and adhesions interfering with function.

Technic.—There is almost invariably enough fat available in the individual operated upon, so that no need arises to resort either to homoplasty or heteroplasty. Autoplasty, therefore, should be the only method employed and, when possible, the graft should be taken from the operative wound. When the fat cannot be obtained from the operative wound, sufficient quantities may be removed from several regions. The favorite sites are the outer aspect of the thigh, the upper part of the arm, the gluteal region, or the lower abdominal wall. When a lipoma is present, it may be satisfactorily employed, especially when cosmetic procedures are attempted. In intra-abdominal surgery, the omentum is available and here the supply is ordinarily adequate.

In using subcutaneous fat the overlying skin is prepared by shaving, cleansing with benzine and alcohol, and an application of the tincture of iodin. An incision is made down to the fatty layer. The skin is undermined on both sides of the wound. The wound is spread open by traction and the fat exposed. Instruments should not be used to grasp the fat and care should be taken not to tear the graft. The surface of the fat is kept moist with salt solution; an incision is made through the fat at one end of the wound and the fat is then gently held with a moist gauze compress; the required amount is dissected away and the graft transferred directly to the previously prepared field. This is unquestionably a better procedure, I believe, than the usual one of placing the graft in saline solution until ready for implantation. After the desired section of fat is removed, the wound is closed by suturing the skin and a firm bandage is applied in order to check the accumulation of serum.

As has been repeatedly emphasized, the field that is to receive the graft should be sterile. A bone cavity must be dry. The fat transplant is tucked into the defect and firmly packed in place. The graft should be larger than seems necessary, especially when used for cosmetic purposes, because of the shrinkage that subsequently occurs. It is not usually necessary to suture the graft in place because it rapidly adheres to the bed. When fat is used to prevent the cutting through of sutures in operations on parenchymatous organs, the graft is placed on the surface of the organ and the suture passed through it. The technic is essentially the same, regardless of the source of the autograft.

Clinical Value.—The fate of a fat transplant is analogous to that of a bone graft. There is a primary degeneration followed either by restitution of the fat by metaplasia or a replacement by fibrous tissue. Although it is commonly maintained that part of the transplant remains viable and is the source of the regenerated fat, the histological changes that are observed do not support this viewpoint.

Clinically, although the transplantation of fat has proved of great value in a variety of conditions, its use is not justified in all the conditions for which it has been advocated. Probably first in importance is the use of the fat graft in plastic surgery of the face. Obliteration of bone cavities with fat is the best known procedure at the present time for the treatment of the condition; obliteration of other dead spaces can often be successfully accomplished by fat grafts. Fat transplantation is sometimes invaluable in abdominal surgery, particularly when doubtful suture lines require support or when sutures have a tendency to cut through parenchymatous organs.

The present status of free fat grafts in the operative treatment of ankylosed joints cannot be justly estimated. In general it may be stated that any completely detached tissue interposed in a joint is not as satisfactory as a pedicled flap and that even the latter should be omitted unless the need of an interposing tissue is imperative.

PERITONEUM

Although omental grafts have long been utilized for the closure of perforations of hollow viscera and for the protection of insecure suture lines, the transplantation of peritoneum as such is a recent development of tissue grafting. Peritoneum was first used by Kocher for the replacement of dural defects. Shortly after, Berezowsky employed a freshly excised hydrocele sac for the same purpose. Lexer practiced peritoneal transplantation in a case of knee-joint grafting, also using a hydrocele sac. Adhesions were found to follow the use of peritoneum for these purposes. Nevertheless, further clinical attempts, based on experimental studies in peritoneal grafting, followed the early and unsatisfactory reports.

The experimental work appears to have been begun because of the evident necessity for using homografts of peritoneum in clinical surgery. The first comprehensive studies were carried out by von Hacker and his associates. He transplanted hernial sacs, preserved by the Foramitti method. This consists of immersion in 5 to 10 per cent formalin solution for two days, in water for the next day, followed by immersion in boiling water and transfer to 95 per cent alcohol. Satisfactory results were ascribed to the use of this prepared peritoneum in the replacement of dural defects and for the envelopment of nerve and tendon sutures. Nevertheless, later observers noted that adhesions occurred when it was used.

Comprehensive experimental studies with fresh and preserved peritoneal grafts were made by Kolaczek. The best results were obtained with fresh homografts. Kolaczek believes that the grafts were largely preserved as such after transplantation but concedes that considerable primary degeneration occurs. He describes extensive adhesions following transplantation of peritoneum, not only in the peritoneal cavity but also in joints. A critical analysis of his histologic reports discloses the fact that complete fibrous tissue replacement ultimately supervenes after grafting of peritoneum.

The only additional work that need be mentioned is the transplantation of combined peritoneum-muscle flaps for the repair of lateral arterial defects, as experimentally performed by Carrel and Guthrie. The purpose was to repair the defect with tissues resembling the arterial wall. Their hypothesis was that the combined transplant of endothelium lined peritoneum and muscle would be preserved as such. Patency of arteries repaired by such transplants was maintained in a few instances but the transplant underwent fibrosis. It will be shown that the use of fascia for the replacement of arterial defects is more efficacious both experimentally and clinically (see Chapter IV).

Homoplastic grafts of peritoneum have been used clinically for a variety of purposes, some of which have been mentioned. Kolaczek has made the most extensive clinical application of the method. He employed transplanted peritoneum around tendon and nerve sutures; for interposition between skin and bone in order to prevent adhesions of the skin after bone operations; for implantation into joints, etc. A detailed description of the technic is unnecessary, for it is identical with that of other tissue grafts and the results are summarized briefly in the following paragraph.

The Clinical Value of Peritoneal Grafts.—A clinical indication for homotransplantation of peritoneum has not been established. The homograft undergoes degeneration and fibrosis, and presents all the disadvantages of homografts of other tissues without any of the compensating advantages of autografts. Other transplants, such as fat or fascia, are far superior for all the purposes for which peritoneum has been advocated.

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CHAPTER IV

THE TRANSPLANTATION OF FASCIA

Clinical and experimental efforts have been made from time to time in the past forty years to transplant free grafts of fascia for various purposes, but the first systematic study of the subject was made in 1909 by Kirschner. In this and in subsequent reports he placed the method on a sound working basis. Kirschner was led to make his investigations in fascial transplantation by the problem of replacing defects of tendons. The use of free tendon grafts for the purpose was not entirely satisfactory for a number of reasons. The amount of tendon tissue that could be obtained autoplastically was limited, the technical difficulties encountered were considerable and experimental tendon transplants did not heal well in place, presumably because of their density. Realizing that the structure of fascia was closely akin to that of tendon, Kirschner studied the possibilities for the use of this tissue, not only for defects of tendons but also for other purposes. He concluded that it was superior to other similar tissues because of the following characteristics:

1. Easy accessibility.
2. Always enough available for autoplasty.
3. Great strength combined with limited elasticity.
4. Tendency to heal in place in a viable state.
5. Ready adaptability to the contours of all fields.

It will be shown that Kirschner did not establish the viability of transplanted fascia by his experiments, but in other respects, and particularly as regards the practical value of the method, little has been added to his fundamental work. Von Saar was the first to cast doubt on the viability of fascial transplants. In experimental replacement of dural defects by fascia he found evidences of degeneration in the transplant as early as two weeks after transference. On the other hand, some experiments by Lewis and Davis appeared to indicate viability of fascial transplants up to thirty-five days, if they were smoothly held in place. Later experiments by Davis, in which fascia was transplanted into almost all the organs and employed to bridge various tissue defects, strongly supported Kirschner's original observations. At the same time these observations were interpreted as proof of viability, not only of autografts, but also of homografts of fascia. Although Davis' corroborative work is of practical value, it lacks proof of the assertions on viability in that the periods of observation are too short and the histologic data are incomplete in the more significant experiments.

Apparently successful experiments in homotransplantation of fascia were reported by Valentin. As an example, the transfer of fascia to replace that of the entire abdominal wall may be cited. In this instance the transplant was found to be in a "viable" state at the end of five months. At the same time, clear evidences of degeneration were to be seen in the reported edematous and infiltrated condition of the graft, and the tissue stained less sharply than the normal. Valentin's experiments can be made the basis for proof of failure of homografts in the biologic sense just as they have been accepted by many as evidence of success. They, too, are not of decisive value. All the work that has been done to establish the viability of fascial transplants cannot be reviewed. It will suffice to say that we believe Kornew's studies can be accepted as offering the only satisfactory evidence of partial viability of autografts of fascia for fairly long periods. Reference will be made later to his work and also to some evidence we have offered on the ultimate fate of transplanted fascia.

The resistant quality of transplanted fascia even under unfavorable circumstances having been recognized, a new field developed by some investigators was its use for reinforcement at operations on visceral defects—in other words, in nonaseptic surroundings. Koenig was the first to employ fascia to support doubtful suture lines in hollow organs and even to bridge visible defects. Neither his results nor those of Hohmeyer were sufficiently convincing to invite any widespread clinical application of the method. In an effort to corroborate their work, Kostenko and Rubaschow, in a considerable number of experiments, found that appreciable defects of hollow viscera could not be bridged by fascia, necrosis and perforation occurring frequently. On the other hand, I have shown, not only experimentally but also clinically, that such defects can readily be bridged by fascial grafts with the use of a different technic. Reference to this aspect of fascial grafting will be made later.

Simultaneously with the evolution of the experimental phase of fascial transplantation, there developed its clinical application in a veritable host of conditions. Many reports of brilliant successes have been made and scarcely any of failures. This gives the impression that fascial transplantation is of inestimable value in surgery. However, until end results, showing failures or partially satisfactory outcome, are recorded as well as the immediate successes, a final opinion as to its value is not justified. My results will, of course, be presented as a personal experience in fascial transplantation, but a report of satisfactory and poor results by a single individual is of no great moment in formulating conclusions of lasting usefulness. Complete data on groups of cases and not merely single case reports are imperative for the proper evaluation of fascial transplantation in surgery.

Histology of Fascia with Special Reference to Fascia Lata.—The microscopic appearance of normal human fascia resembles closely that of animals used in experimental work (dog, rabbit, etc.). Since fascia lata will be shown to be superior to other fasciae for transplantation purposes, a knowledge of its appearance is desirable. This is especially necessary because some interpretations of supposed retention of a normal state (viability) appear to have been based on inadequate knowledge of the histology of this tissue.

Throughout most of its extent, fascia lata is composed of three layers. The fibers of the middle, the most dense and thickest of the three, run in the vertical axis so that they are chiefly seen in their length in longitudinal sections when examined under the microscope. The fibers of the inner and outer layers course at right angles to the main median layer. Each of the strata is composed of closely woven bundles of wavy connective tissue, the cells having elongated nuclei. The microscopic appearance resembles that of tendon tissue. The primary bundles are interspersed with a loose connective tissue also composed of cells with long nuclei, comprising the so-called secondary bundles. The median portion is joined to the inner and outer layers by loose connective tissue, carrying the blood-vessels and most of the elastic fibers. The latter are numerous, making thick strands that run for the greater part in the vertical axis. Elastic fibers are to be found between the three layers and also on the external aspects of the outer layers, while fine branches extend into the three layers forming a true elastic network penetrating between the cells.

Strength and Elasticity.—Of the various fasciae in the human body, the fascia lata is the strongest, particularly in the lower and most posterior portion. Kirschner demonstrated its great resistance to mechanical traction. The densest portion of the fascia lata can scarely be torn when traction is made between flat clamps. It cannot, of course, resist as much traction by sutures, because separation would begin about the stitch holes. If fascial transplants are to be subjected to great tension, mattress sutures should be used to distribute the pull. Many clinical as well as experimental observations have established the fact that fascial grafts can withstand powerful strain. Thus fascia has been successfully used to bridge the gap in a torn biceps muscle, to replace the tendo achillis, to bridge a defect of the abdominal wall, etc. As a result of its quality of minimal shrinking when transplanted, the size of a fascial transplant need only be slightly greater than that of the defect to be bridged or the area to be covered.

Availability.—Fascia lata lies under the skin throughout its course. Whether the upper and thinnest or the lower and strongest portion is desired, a simple incision through the skin effects an adequate exposure. Of the other fasciae, that of the abdominal wall most nearly approaches fascia lata in character, but it cannot, of course, be sacrificed in as large amounts, and it is not as readily detachable. Occasionally fascia present in an operative field can be satisfactorily employed, but in general consider fascia lata the ideal material regardless of the field of operation.

All the evidence at hand proves that the sacrifice of fascia lata is harmless. In all the cases I have been able to follow, there have been no functional disturbances, even where large sections of the lowest portion had been removed. Hernia of the muscle has but rarely occurred in my series and I have not seen reports of hernia following excision of fascia lata. Autoplasty having an established superiority over homoplasty, the practically unlimited quantity of fascia lata that can be obtained from an individual is an important advantage. It is difficult to visualize any situation in which the available amount of fascia lata will not suffice for the purpose.

Adaptability.—In this respect fascia has a great advantage over a number of other tissues used for grafting (periosteum, fat, bone, etc.). There is no difficulty in suturing or fitting it into place. Stitches hold well in fascia, and folds, imbrications or hollow cylinders of the graft can be made by appropriate sutures. Flat or curved surfaces are equally adaptable for the use of this tissue.

Transplantability—*Viability.*—Fascia is one of the most readily transplantable of all the tissues for reasons previously indicated (see Chapter I). It is a simple tissue, relatively poor in cells and blood vessels. All observers are agreed that fascia heals in place with minimal reaction, and even under unfavorable circumstances. In our personal experience there has not been a single instance in which transplanted fascia has been extruded even in cases in which infection had been present or had appeared after operation.

That fascia is a readily transplantable tissue is a well-established fact, but there is no general concurrence of opinion as to its viability and hence as to its ultimate fate when transplanted. The early phenomena occurring about an autograft of fascia are agreed upon by all investigators. The transplant is promptly covered by a layer of fibrin rich in leukocytes, that gradually undergoes organization. A thick zone of cellular granulation tissue is found to surround the graft in about two weeks. The staining quality of the fascial cells as well as the intercellular substance suffers almost from the outset, and degeneration of at least some of the cells unquestionably occurs.

Apparent recession of the degenerative phenomena in the graft is seen in the succeeding weeks. Is this really the case or are we dealing with the early evidences of gradual replacement? The question of the persistence or replacement of fascial transplants has been widely discussed. A large part of the experimental studies undertaken to settle this moot point must be ruled out because the periods of observation after transplantation are too brief. Studies made over prolonged periods (six months to a year) have led to divergent conclusions.

Exceedingly few opportunities have been found for determining the histologic condition of fascial transplants in human beings after long intervals. The case reported by Denk is, therefore, of unusual interest. A fascial transplant into a dural defect was examined eleven months after its implantation and showed replacement by a fibrous tissue interwoven with elastic fibers. I have reported the macroscopic appearance, after one and a half years, of a fascial transplant sutured into a dural defect. It was barely distinguishable from the adjacent dura and not adherent to the underlying brain surface, but here, too, replacement by fibrous tissue from the host may have occurred.

Concerning the experimental observations over longer periods, a difference in the appearance of the transplant exists, depending upon whether or not it had been subjected to mechanical strain. Thus Kleinschmidt reported experiments made under both conditions, the grafts being examined several months after implantation. These reports showed that when the graft was merely placed under the skin, very slight degenerative changes and replacement phenomena were noted. Grafts examined after implantation into muscle defects, and, therefore, subjected to strain, showed alterations in thickness, partial disappearance of portions not under tension, and partial replacement. Similar changes were observed by Kornew in an intensive study of this aspect of the subject. Fascia transplanted into defects of tendons was found to undergo gradual transformation into a fibrous tissue, intimately interwoven with, and almost indistinguishable from, the ends of the resected tendon. The most significant of Kornew's observations, and one widely quoted as establishing the permanent viability of transplanted fascia, is the description of a graft implanted into a pleural defect and examined at the end of one year. The specimen showed that the physical structure of the transplant, although altered, was retained in a general way. Here ended any identity with the microscopic appearance of normal fascia. Although Kornew states that the transplant has remained viable as such, his own histologic report clearly indicates that this is not the case:

The transplanted tissue is intimately interwoven with the surrounding tissue, its transversely divided bundles being prominent, the longitudinally sectioned ones poorly defined. In higher magnification . . . the tissue adjacent to the fascia on its superficial surface presents a dense layer of connective tissue. It is most difficult to determine if we are dealing here with a layer of fascia or scar tissue, all the more so because elastic fibers are present to the same extent as in the adjacent well-defined fascial layer. The endofascial tissue is of definite fibrous character with a well-defined development of small blood vessels. The contours of the transversely sectioned fascial layer are to be clearly seen and *the infiltration of younger elements* into this layer is barely visible in its central portion. Between the two layers of transversely divided bundles is a thin layer of wavy connective tissue containing many capillaries. In addition, *this layer contains fat cells both singly and in whole rows,* which are not to be found, however, in the actual fascial bundles.

Upon examination nearer the pleural surface an inner longitudinal layer is found, narrower than the transversely divided bundle but presenting a similar definite tendinous structure with well-stained nuclei. In some places the fibers are separated by *younger connective tissue* fusing with scar tissue towards the pleural surface. The inner aspect of the transplant does not present the regular architecture of the outer; its fibers run in various directions, its *limits are not well defined,* and there are present *numerous elongated and oval cells* with large nuclei.

Thus phenomena of degeneration, vascularization, and replacement are manifest at the end of one year in this widely quoted instance of supposedly permanent viability. That part of the transplant was still viable cannot be gainsaid, although there is no conclusive evidence that the tissue described by Kornew as fascia is not really a layer of connective tissue that has completely replaced the original transplant. Mimicry of the appearance of any original graft by the replacing tissue is a frequent occurrence. In any event, it is clear that permanent viability cannot be accepted as established when widespread replacement phenomena and evidences of degeneration exist.

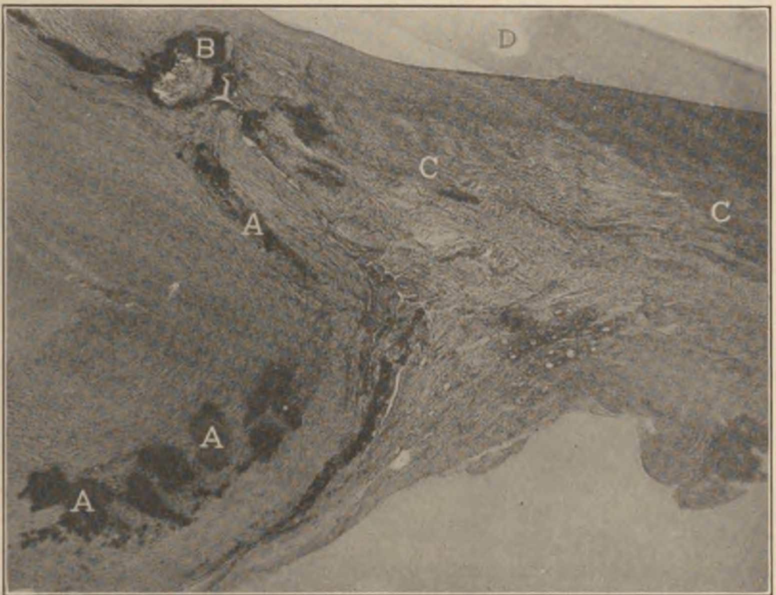

FIG. 24.—RESULTS OF FASCIAL TRANSPLANTATION INTO A DEFECT OF THE AORTA.

Calcification in the wall of the abdominal aorta at *A*, *A*, *A*, and about the silk suture at *B*. The transplant, *C*, *C*, has undergone fibrous tissue replacement, but the surface facing the lumen, *D*, is smooth and covered by flat cells (six months after operation).

Our own experiments, in which fascia was transplanted into defects of the diaphragm, of the walls of arteries, of the pleura, etc., show that the general architecture of the graft is preserved for as long as six months to one year, but careful examination reveals the fact that the transplant is not preserved as such, but has been gradually replaced by fibrous connective tissue closely resembling it. That the replacement is very gradual is evident from the fact that the phenomena are not complete after the long periods alluded to. The newly laid down tissue cannot be termed cicatricial or scar tissue, the result of degeneration of the transplant. It would be more accurate to describe it as a cellular connective tissue occupying the framework and largely maintaining the form of the original graft. We were unable to determine if elastic fibers found in the replacing tissue are derived from the graft or from the bed in which it was placed.

All the experimental work carried out to establish the ultimate fate of fascial grafts cannot be reviewed. Enough has been presented to indicate that the proof of permanent viability has not been established. Permanent function of the transplant as such cannot, therefore, be anticipated. However, replacement phenomena are of very gradual evolution, the size and architecture of the graft being maintained as a rule. As a result, the purpose for which the transplantation has been performed can be ordinarily achieved. The ready transplantability of fascia and, therefore, its great practical usefulness have been established on a solid basis.

Technic.—Fascia lata is loosely attached to the overlying skin and almost completely free from the underlying muscle. It is thickest and strongest in the lowermost portion. Sections taken directly above the posterolateral aspect of the knee-joint will ordinarily best serve the purpose for which a fascial transplant is employed. Grafts from the middle or upper part of the thigh can, of course, be taken when thinner sections are desired. For removal at the site of election, it is best to cross the knee over the opposite one and to rotate the leg internally. The fascia is thus put on the stretch and the most desirable portion will then lie directly under the skin incision. A straight, or curved, vertical incision through the skin having been made, the skin margins are clipped to towels about the wound. Slight dissection readily detaches the skin from the fascia, but in cleanly removing the subcutaneous tissue from the glistening surface of the fascia, great care must be taken to avoid bruising or nicking the graft. In the discussion of the general principles of tissue transplantation, we indicated that it was best first to prepare the field for the reception of a graft and then to detach the tissue and transfer it directly to its bed. Placing the graft in a solution while the field is being prepared is particularly undesirable in the case of fascia, for it becomes soggy and does not hold sutures as well as if this step were avoided.

The technic we employ to detach a large fascial graft minimizes the trauma incidental to its removal, accurately marks its boundaries, and renders the graft ready for implantation. The size and shape of the proposed transplant having been measured by a sterilized steel tape or by a pattern that has been cut, sharp nicks are made through the fascia at the four corners, exposing the musculature. Fine separately threaded sutures are passed at these corners, the needles being left attached. The fascia lata is then detached with scissors by cutting around the four points in the desired pattern. The graft being freed from the underlying musculature by slight dissection through the loose thin layer of connective tissue, it is lifted by the four sutures and transferred to its bed. In this procedure forceps are not applied to the graft at any time.

When small or rolled-up sections of fascia are required, the traction suture method is unnecessary. That special technic will be found very useful when fixation over a flat or cylindrically shaped defect is indicated, for the graft will not fold or roll up, and is ready for immediate fixation. The four needles are passed at appropriate points through the bed prepared to receive the graft. In most instances, a continuous suture is then made between the fixed points, but interrupted sutures are chiefly used in transplanting fascia into such fields as tendon defects. We have stated our reasons for preferring fine silk for suture material and have indicated the advantages of the continuous stitch (see Chapter I). Regardless of the type of suture, the stitches should be sufficiently far apart to eliminate the possibility of strangulation of the portions of the transplant included between them. We believe that necrosis is more apt to occur in fascial than in other varieties of tissue transplants, such as fat or muscle, from neglect of this precaution. The general principles of technic that already have

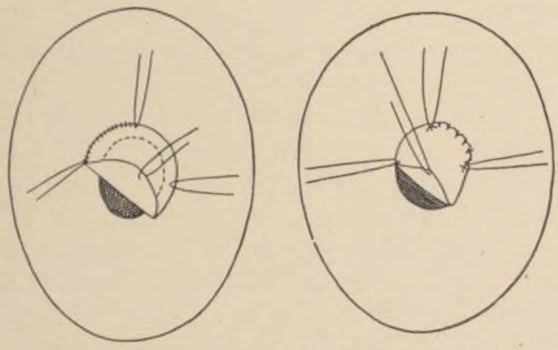

FIG. 25.—METHOD OF TRANSPLANTING FASCIA.

Diagram on the left shows the usual method, that is, over the defect. The method used in the clinical and experimental work described in the text, consisting in fixing the graft into the defect, is illustrated on the right.

been alluded to should, of course, be as scrupulously observed in fascial as in any other tissue transplantations.

The final and perhaps the most important technical question concerns the method of fixing a fascial transplant in a defect. All writers advise that it should be sutured *over* the gap to be bridged, with a considerable overlap on all sides. That such a procedure is desirable in some situations (fascial cylinders for nerve or tendon defects, etc.) cannot be questioned, and, while in other situations it appears to be immaterial what method is used, for most cases *it is essential that the transplant should be sutured into the defect.* By this I mean that the cut margin of the fascia should be approximated to the cut margin of the bed to which it is attached. In so treating a defect of the dura, for example, the edges of the fascia should be approximated by the sutures to the edges of the dura. The theoretical advantages of this method over the overlapping one are as follows: greater ease of organization and vascularization proceeding from the tissue margins of the host; the elimination of a dead space between the under surface of the graft and the adjacent one of the host; approximation of the graft to raw edges rather than to surfaces; greater tensile strength and better control of leakage. That these theoretical advantages hold true in practice was shown clearly by some experiments I conducted. Investigators had previously failed in attempts to bridge appreciable defects of hollow viscera by suturing fascia over them. In our experiments we were able to bridge successfully large defects of such organs by the technic of suturing fascia into them. Other factors not having any evident bearing, the results that were obtained can be ascribed only to the technic that was employed. It is the method that has yielded the best clinical results in our hands and the one we advocate for fascial transplantation.

FASCIAL GRAFTING IN SURGERY

Transplantation of Fascia and Tendon for Defects of Tendons.—The repair of divided tendons and the replacement of long defects in tendons is a common surgical problem. Recent traumatic lesions can usually be adequately cared for by direct suture or by plastic operations on the ends of the severed tendon. Conditions often arise, however, in which such relatively simple procedures cannot be practiced.

Many methods have been evolved for the surgical treatment of the more difficult cases. The one that has been most popular until recent years is Lange's method of implantation of paraffined silk. He reported hundreds of cases, chiefly for the correction of paralytic deformities, with very few instances in which the silk acted as a foreign body and was extruded at a later date. Although Lange's method has had a wide sphere of usefulness, its drawbacks are evident. In addition to the possibility of late suppuration that always exists, the slightest infection occurring at the time of operation may readily be followed by the prompt expulsion of the silk strand. Cicatricial tissue appearing in the operative field under such circumstances may render conditions worse than they were before operation and certainly increase the difficulties of a subsequent reparative procedure. Necrosis of the tendon as a result of tension by the silk suture has not been uncommon. Owing to adhesions about the silk strand, the method is not dependable when mobility between and not merely fixation of the ends of the tendon is essential. Finally Lange's procedure is not readily applicable in the presence of scar tissue following tendon sheath infections.

Nevertheless any procedure proposed as a substitute for a method of proved practical value must offer manifest advantages. Many writers have expressed great enthusiasm for the use of living tissues for the purpose. It may be said at once that, albeit the experimental evidence is most encouraging, enough clinical material has not as yet been accumulated to establish the superiority of living material over silk for the replacement of tendon defects.

In 1909, Rehn advocated tendon tissue and Kirschner, fascia, as implants for tendon defects. Rehn maintained that his transplants of tendon showed persistent viability with retention of the gliding peritendinal surfaces. The latter were thought by him to be essential for the functional success of a transplant into a tendon defect. Realizing the limited amount of tendon tissue that could be obtained for autoplasty, he studied homotransplantation of tendons and believed the results were quite satisfactory. The pioneer work of Rehn in this field should be recognized, but his results cannot be accepted unqualifiedly. A perusal of his publications shows that he has not demonstrated an indefinite viability of tendon transplants, that the supposed retention of gliding surfaces may well be new tissue laid down by the host, and that homotransplantation of tendons has not proved to be as satisfactory as autotransplantation. Clinically, a few cases of successful homotransplantations as well as autotransplantations of tendons have been reported by Lexer and Rehn, as well as by others. But failures have also been described, particularly after homotransplantation. We can only conclude at the present time that the latter is not practicable and that tendon autoplasty has a limited sphere of usefulness.

There are a number of advantages of fascia over tendon as a material for the replacement of tendon defects. The required amount can always be obtained autoplastically. Its flat surfaces permit maximal contact with the tissues of the host, and an early degeneration of central portions does not occur as in tendon grafts. Fascia can be used in the form of an enveloping membrane about the separated ends of tendons. It may, therefore, be more favorably placed for firm union with tendons. Finally, fascia can be more readily patterned to fit any tendon defect for which a graft is required.

An analysis of the experimental studies on fascial transplantation into defects of tendons shows that the graft gradually undergoes replacement by fibrous tissue. This newly formed tissue is considerably thicker than the original graft if there has been traction exerted on the transplant by the ends of the tendon. There is but slight tendency to contraction of the replacing fibrous tissue, owing to the fact that it only very gradually permeates, over a period of from two to four months, the slowly disappearing graft, and is laid down in a pattern determined by and similar to the fascial transplant.

Technic.—The technic for the replacement of tendon defects by autografts of tendons is simplified by the use of the ingenious clamp devised by Bunnell. The method of using the clamp is seen in the accompanying illustrations.

The technic of fascial transplantation for tendon defects is, however, simpler than that of tendon transplantation. The tendon ends are freely exposed by a skin flap whenever possible so that the cutaneous cicatrix will not overlay the graft. The field is prepared, and traction sutures are passed through the ends of the severed tendon to approximate them for the desired distance. Enough of the densest portion of the fascia lata, the iliotibial band near the knee-joint, is removed to bridge the gap and to overlap each tendon end for a distance of 3 to 4 cm. Held by four traction sutures, the graft is placed beneath the ends of the tendons and is secured to the proximal stump by three or four interrupted sutures. It is fixed similarly to the distal stump. The trac-

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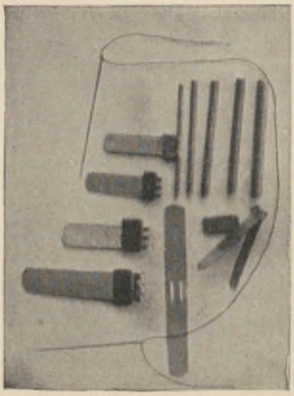

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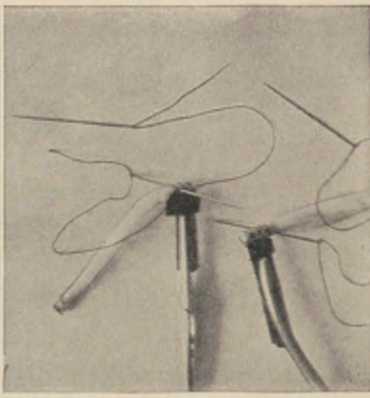

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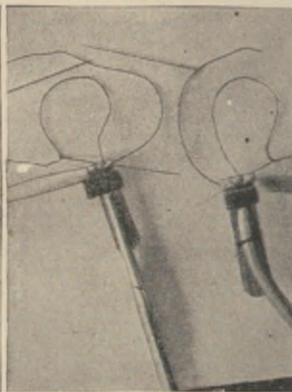

FIG. 26.—TENDON CLAMPS WITH RODS FOR SHAPING THEM.

FIG. 27.—SUTURING ENDS OF TENDONS, USING TENDON CLAMPS. TO RIGHT, FIRST NEEDLE IS STARTING; TO LEFT, SECOND NEEDLE IS STARTING AND FIRST NEEDLE HAS FINISHED.

FIG. 28.—TO RIGHT, SECOND NEEDLE IS ENTERING PROXIMAL SLIT AND EMERGING THROUGH DISTAL SLIT. FIRST NEEDLE HAS FINISHED. TO LEFT, SECOND NEEDLE IS MAKING THE LAST STITCH AND FIRST NEEDLE HAS FINISHED (Bunnell).

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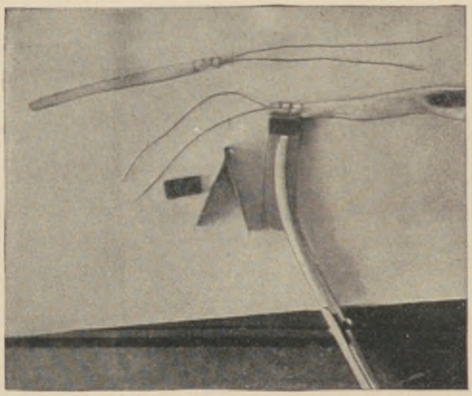

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FIG. 29.—SUTURES PLACED; CLAMP REMOVED FROM THE TENDON.

FIG. 30.—SUTURES HAVE BEEN TIED, UNITING THE TENDON ENDS TOGETHER (Bunnell).

tion sutures on the tendons are now withdrawn and the longitudinal borders of the fascia are sutured together. The result is a tubular envelope of fascia inclosing the ends of the tendon and bridging the gap.

The grafting of fat-fascial flaps has been advocated to supply a smoothly gliding surface. The argument for the use of this type of transplant is evidently based on the erroneous notion that there is a permanent viability of the fat; in practice, a combined fat-fascial graft would

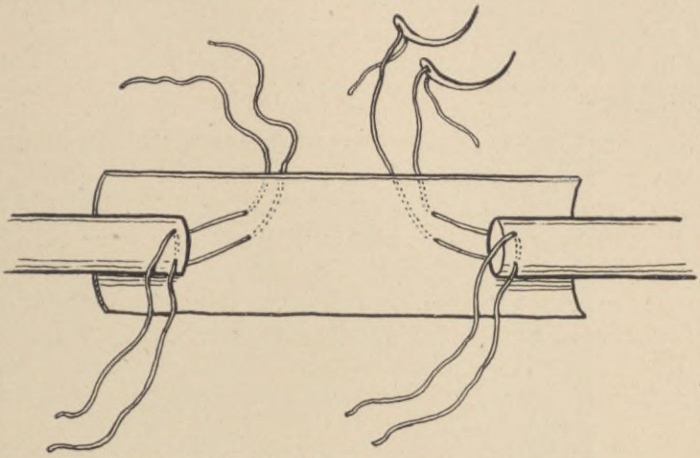

FIG. 31.—THE TECHNIC OF FASCIAL GRAFTING FOR A TENDON DEFECT.

The sheet of fascia is placed beneath the ends of the tendon. Two sutures are passed through each end of the tendon. The deep pair are being passed through the graft so that the ends of the tendon are drawn towards each other when these sutures are tied.

tend to defeat the object of the operation by the formation of adhesions resulting from the fat replacing tissue (see Chapter III).

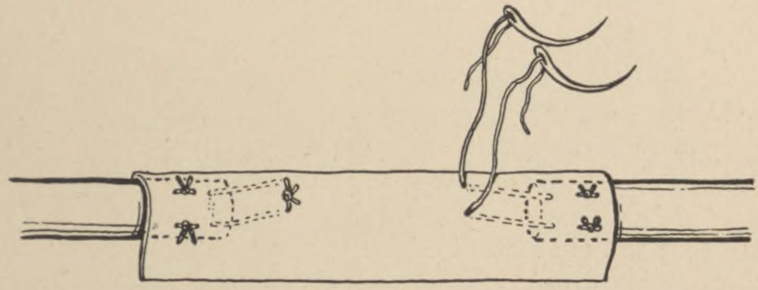

FIG. 32.—POSTERIOR VIEW, TO SHOW THE COMPLETION OF THE DEEP SUTURES AND THE ATTACHMENT OF TENDON TO GRAFT BY ADDITIONAL SUTURES.

Early passive and active motions are imperative in the after treatment for the same reasons that apply to simple tendon suture. Passive

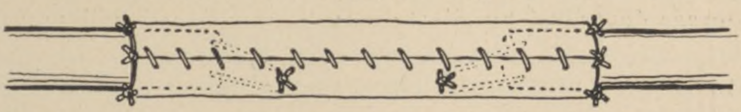

FIG. 33.—THE ANTERIOR TRACTION SUTURES ON THE ENDS OF THE TENDON ARE COMPLETED, THE CUFF OF FASCIA SUTURED TO THE ADJACENT SURFACE OF TENDON, AND THE MARGINS OF THE GRAFT ARE APPROXIMATED BY A CONTINUOUS SUTURE.

motion is begun on the day after operation, and active motion on the third day, and undoubtedly this routine has been a factor in some of the satisfactory results obtained, regardless of whether tendon or fascial transplants are employed.

Results.—Brief reference has been made to the clinical results of autotransplantation and homotransplantation of tendons. Concerning the results of fascial grafting for tendon defects, not enough clinical material has as yet appeared to afford a basis for final conclusions as to its value. A number of cases have been reported, most of them either entirely or partially successful.

FIG. 34.—MAXIMAL EXTENSION OF SECOND, THIRD, AND FOURTH FINGERS.
The extensor tendons to these fingers had been severed above the wrist several weeks before.

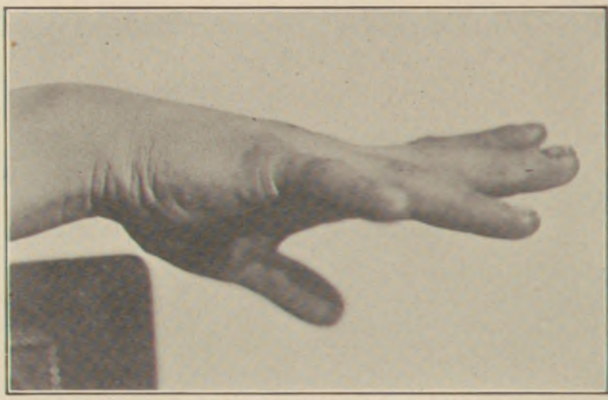

FIG. 35.—RESULT ONE WEEK AFTER FASCIAL TRANSPLANT FOR THE TENDON DEFECTS.
This illustrates the advantages of early mobilization. The patient returned to heavy work three weeks after operation. The end result is full power and function.

Two cases described by Giertz may be mentioned as illustrating the satisfactory outcome of fascial grafting for wide defects. In one patient, the long and short extensor tendons of the thumb had been destroyed by an infection and were buried in scar tissue. After their mobilization, the stumps could not be approximated. A sheet of fascia lata, 15 cm. long, was implanted according to the technic already described. Active motion was begun on the second day. A perfect result both in range of motion and in power was obtained, as determined at an examination five months after operation. In the second case, the long flexor tendon of the thumb was destroyed in a tendon sheath infection, with subsequent flexion contracture. The cicatricial tissue was excised. One end of the tendon was found at the distal phalanx, the other was not of normal appearance until the dissection was carried to the level of the wrist joint. A sheet of fascia lata 10 cm. long was implanted. The transplant healed in place despite some separation of the wound. An examination four months later showed that extension was somewhat hindered by the weblike cicatrix. Flexion of the thumb existed to a limited extent; the other motions were normal. The economic result was satisfactory.

A case reported by Payr is an interesting illustration of combined skin and fascial transplantation. The method he employed offers a solution for the difficult problem of extensive scar tissue and finger contractures following infection. The operation was done in two stages. At the first, all the cicatricial tissue in the region of the tendon defect of the finger was excised. The wound was left open and a pedicled flap was raised from the thigh and attached. The base of the pedicle was divided at the usual time and the flap healed well in place on the finger. The second stage was carried out three months later. The stumps of the tendon were exposed by separate incisions and the transplanted skin flap was undermined. The tube of fascia was drawn through, and sutured around the ends of the tendons in the usual way. A fair degree of flexion of the finger was present at the end of two weeks, and there was progressive improvement in function up to the time of the discharge of the patient, six weeks after operation.

Our own experience is limited to five cases. The technic of operation need not be detailed as it was almost identical with that already described. Two of the cases were contractures following tendon sheath infections. In one, almost perfect function followed operation as evidenced by observation over a period of a year. A partial result was obtained in the other, only slight flexion of the finger existing at the end of two months. The third case was a recent wound with a wide defect of the long flexor tendons of the little finger. No functional result was obtained in this case, operated upon by the house surgeon under our supervision. It is only fair to state that the patient was very refractory and early motions could not be practiced satisfactorily. Operation in the fourth case was followed by a perfect result and constitutes a type of lesion for which fascial transplantation has not as yet been employed. The patient, a powerfully built man, was slashed with a knife across the bend of the elbow and suffered a division of the biceps tendon as well as other structures at the elbow. Operation for the tendon lesion was performed three weeks after the injury. The severed ends could not be approximated when the elbow was acutely flexed. A sheet of fascia 12 cm. long was implanted with the usual technic. Some difficulty was encountered in surrounding the short distal stump and a portion of the bicipital fascia was included. Perfect function, that is, full range and power in the motions at the elbow, existed at the end of four months. The fifth case is shown in Figs. 35 and 36.

Kirschner reported two cases of fascial transplantation for defects of tendons of the fingers, with a satisfactory result in one and an incomplete result in the other. He also advocated the use of fascial envelopes for the reinforcement of the ordinary tendon suture. Such a procedure appears undesirable, for permanent fixation of the tendon may occur as the result of organization of the transplant. This is a possible outcome

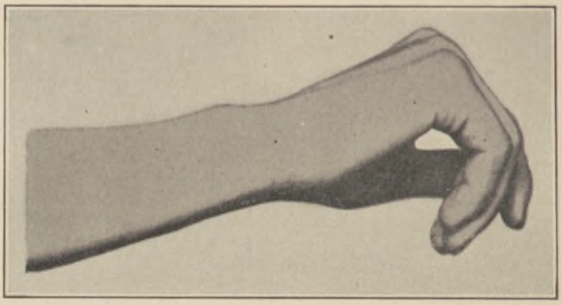

FIG. 36.—MAXIMAL EXTENSION OF THE FINGERS BEFORE OPERATION (Kirschner).

to which the patient should not be subjected unless the indication is imperative.

In conclusion, it may be said that some excellent and some poor results have followed the transplantation of fascia for tendon defects. Not enough clinical material has as yet appeared and, therefore, the value of the method cannot properly be estimated. Some of the cases that have been reported demonstrate that fascial transplantation may

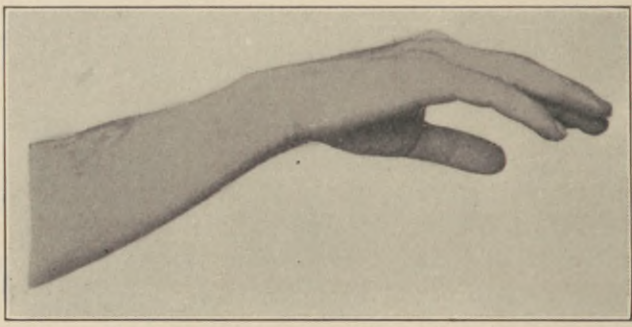

FIG. 37.—FASCIAL TRANSPLANTATION FOR DEFECTS OF EXTENSOR TENDONS. Maximal extension after operation (Kirschner).

succeed in solving a difficult problem for which there are no other satisfactory alternative procedures. Hence it is justifiable to urge further trial of the method for the treatment of wide defects of tendons that cannot be approximated by simple suture or by satisfactory plastic operations on the tendons.

Habitual and Unreduced Dislocation of the Shoulder.—The only efficacious method of treating this condition is by operation. Two types of operation are commonly employed. One consists in reefing the relaxed capsule of the joint, the other in reimplantation of the musculature attached to the upper humerus. Without entering into the details of these procedures and of their various modification, it may be said that recurrences not infrequently follow operation and that limited function at the shoulder often accompanies satisfactory open reduction of the dislocation.

Kirschner raised the question of using a fascial transplant as a substitute for the relaxed ligaments. He advocated a complicated operation worked out on the cadaver. It consists essentially in implanting a strip of fascia lata from the acromion around the inner aspect of the anatomical neck of the humerus. The difficult operative technic is an objection. Besides, the principle involved appears unsound. Absolute dependence is placed upon the fascial transplant persisting as such and remaining unstretched and attached, despite the tremendous leverage to which it will be subjected. Furthermore there can be no real assurance that the transplant will not shift from the position in which it is fixed.

A procedure we employed in one case of frequently recurring dislocation of the shoulder consisted in reefing the thinned capsule over the antero-internal aspect of the joint and then attaching a broad sheet of fascia over the imbricated area under moderate tension. The patient was last examined two years after operation; motion was normal and there was no recurrence of dislocation. In this case, cure might have been effected by the simple reefing operation, but that is not the usual experience. Kirschner quoted Heller as having employed the identical procedure in a case in which the immediate result was satisfactory; a later report was not made. He expressed grave doubt as to whether a simple reefing operation reinforced by a fascial transplant would suffice to prevent a recurrence.

A successful result was reported by Payr, who used fascial grafts in another way. The anterior surface of the capsule was exposed and a triangular flap of fascia lata was attached to it. The long mesial border of the triangle was sutured to the adjacent pectoralis major. Three layers of reinforcing sutures were passed between transplant and underlying capsule. The upper angle of the graft was firmly anchored to the coracoid process under tension. A posterior incision was then made, retracting the deltoid laterally. A second triangular sheet of fascia was similarly implanted on the posterior surface of the capsule of the joint, the mesial border being fixed under tension to the infraspinatus and teres minor. The result attained was an approximation of the head of the humerus to the glenoid fossa by leverage upon fixed points.

A simple open reduction with suture of the capsule is said to be adequate for the treatment of old *unreduced dislocations* of the shoulder, but we have seen recurrence of dislocation follow such operations. They have also occurred when capsular reefing has been added. The reason is not difficult to find. In addition to the tear, the capsule has been stretched and has become atrophic as the result of the unreduced dislocation, and cannot regain its former texture after the head of the bone has been replaced. The antero-internal portion of the capsule suffers most in the usual type of dislocation. For these reasons we were led to employ fascial transplantation over this aspect of the joint in the operative treatment of unreduced subcoracoid dislocation in two cases. The results were satisfactory in both instances.

As far as is known, this method has not been employed by others and, although our experience is small, we are led to believe that the theoretical and practical basis for the operation is sound. In one case, there was a subcoracoid dislocation of eight weeks' duration; the capsule about the rent was flabby and thin, and was freely excised until approximately normal capsule was reached. The margins could not be brought together without undue tension. A sheet of fascia lata 5 by 7 cm. was snugly sutured to the cut margins of the capsule. Perfect function followed operation and there has been no recurrence of the dislocation after five years. Another case, recently operated upon, was of a different type, and one much less satisfactory for treatment by reefing. A debilitated man, sixty years old, had had an unreduced subcoracoid dislocation for four weeks. Several attempts at reduction had failed. At operation there was no visible rent in the capsule. The latter was found to be thin and friable and without any resemblance to normal capsule over a large part of its antero-internal aspect. This was presumably the result of inadequate repair of the rent. The joint was opened, masses of fibrin adherent to the inner surface of the capsule were removed, and the dislocation reduced. The altered portion of the capsule was in large part excised, leaving a defect about 7 by 5 cm., which I bridged with a sheet of fascia lata, suturing the latter in place under slight tension. Care was taken to pass the sutures through the capsule well away from the margin of the defect in order to attach the transplant to approximately normal tissue. As already stated the early result was satisfactory, but, in view of the lesion found at operation, a good ultimate result is not anticipated with any certainty.

All the reported cases, and those in our personal experience in which fascial transplantation has been used for dislocation of the shoulder, have been reviewed. No broad generalization can justly be made from this very limited material. However, a start has been made toward proving that the method will be found of great value in the operative treatment of shoulder dislocations, and that it bids fair to replace the older surgical procedures.

Habitual Dislocation of the Patella.—Various operative measures have been successful in the treatment of recurring dislocation of the patella. They consist, in principle, in excision of the relaxed internal expansion of the capsule of the joint, in the common variety of external or lateral luxation of the patella, and suture of the defect. A type of operation involving transplantation, that has been satisfactorily employed, consists first in the excision of the excess portion of the internal expansion. Then an incision in the external expansion is made, after which the patella is drawn inwards to its normal position. The resulting gap in the external expansion is covered by the portion of the internal expansion that had been removed, which is then sutured in place. One cannot, however, be impressed with the desirability of transplanting a stretched and atrophic capsular ligament. In any event, the operative procedures usually employed for dislocation of the patella are by no means always successful and they involve free opening of the knee-joint.

Fascial transplantation has been advocated and successfully used in the treatment of the condition. The operation is exceedingly simple and does not involve the opening of the knee-joint. After the relaxed internal expansion has been plicated, a sheet of fascia lata is sutured over it. One border of the transplant is firmly secured to the internal margin of the patella. The other borders are fixed to the capsule under sufficient tension to hold the patella in its normal position. In one case this operation was performed after another type of operative procedure had failed. The patient was cured and the function of the knee-joint was normal during two years' observation.

An operative procedure for dislocation of the patella, involving fascial transplantation, is sound and simple, and is an important consideration in operations about the knee-joint. In habitual dislocation of the shoulder the whole capsule is usually involved so that the result may often remain in doubt. On the other hand, the lesion is largely or entirely limited to one part of the capsule in habitual dislocation of the patella. Operative procedures involving infolding of the stretched and atrophic capsule of the shoulder have often failed and failure after similar operations at the knee-joint is not surprising. Adequate support can no more be anticipated from the repair of an atrophic capsule than from the repair of atrophic tissues elsewhere. The operation of fascial transplantation, therefore, appears ideal for the surgical treatment of habitual dislocation of the patella.

Traumatic Lesions of the Capsule and Ligaments of the Knee-joint.—Fascial grafts have been successfully used for the replacement of torn external and internal ligaments of the knee-joint and should prove of definite value in the surgical treatment of such lesions. Stability of the knee-joint is essential for function and a grafted sheet or band of fascia is sufficiently resistant to be capable of replacing torn or greatly stretched ligaments. It is needless to say that such operations are not to be considered unless the indications are clear.

During the World War there must have been many opportunities to make practical use of fascial transplantation for wounds of the knee-joint. To what extent the method was used is unknown. In our personal experience it was of inestimable value in a number of instances, knee-joints otherwise doomed being undoubtedly saved by the procedure. To quote a case in which the ultimate result is known: the soiled perforating wound from a high explosive missile was situated over the inner aspect of the knee-joint, the articular surfaces being widely exposed. At operation, six hours after the wound had been sustained, the devitalized tissues were excised. The patella had been in large part destroyed and the loose fragments were detached. Fragments loosened from the internal condyle of the femur were removed. The soft parts and skin could not be approximated. A large sheet of fascia lata was detached and sutured into the capsular defect. One border was attached to the patellar ligament and quadriceps tendon and about the remainder of the patella, the opposite border to the margin of the torn capsule, and the other borders were secured to the adjacent tissues. A skin flap was turned down to cover the transplant and sutured in place. The wound healed by primary union. Skin grafts were later applied to the defect left by detachment of the skin flap. The function of the knee-joint, as reported two years after operation, was good. Flexion was somewhat limited but extension was complete. There was no instability of the joint except with violent exercise.

Dislocation of Tendons.—The use of a fascial strip was advocated by Kirschner for the treatment of dislocation of the peroneal tendons at the external malleolus. In a discussion of the various operations that have been performed for the condition, he pointed out that simple suture does not suffice and that the other operations are complicated and, at the same time, do not bring about the normal relations of the tendons to the ankle. The transplantation of a strip of fascia, fixing it above to the external malleolus and below to the os calcis, would, theoretically, supply the lacking ligamentous support. The operation has not as yet been performed but should prove a satisfactory one. Similar procedures have been suggested for recurring dislocation of tendons in other regions.

Flat-foot.—A discussion of the varying etiology and pathology of flat-foot would be out of place. It suffices to say that operative treatment is found to be indicated in some cases presenting advanced degrees of subluxation in the tarsal joints. Some of the methods that are employed consist, in principle, in the approximation of bony prominences on the internal aspect of the foot by the use of various tissues. It is not easy to understand how the weight of the body can be supported adequately as the result of such procedures, yet successful operations have been reported. Katzenstein described a satisfactory result after the implantation of periosteum. If a transplant is to be used for the purpose, fascia would appear to be more serviceable. Several satisfactory results have been described, particularly after the preliminary correction of the foot and retention of the corrected position in plaster of Paris. All that can be said of the use of the fascial graft in the operative treatment of flat-foot and other deformities of the foot for which it has been advocated is that considerable clinical material must be accumulated to demonstrate any advantages over the usual operative methods.

Divided and Paralyzed Muscles.—The use of fascial graft for this purpose is of distinct clinical value in a variety of conditions and is based upon sound experimental evidence. It has been shown that fascial transplants sutured into gaps in muscles heal well in place and that the replacing tissue fuses intimately with the adjacent musculature. The pull of a muscle is thus transmitted through the fibrous tissue that is laid down and the functional result is satisfactory.

A striking clinical result in a case of rupture of the biceps is reported by Payr. The tendon of the long head of the biceps had been torn from the belly of the muscle and considerable loss of function resulted. Upon

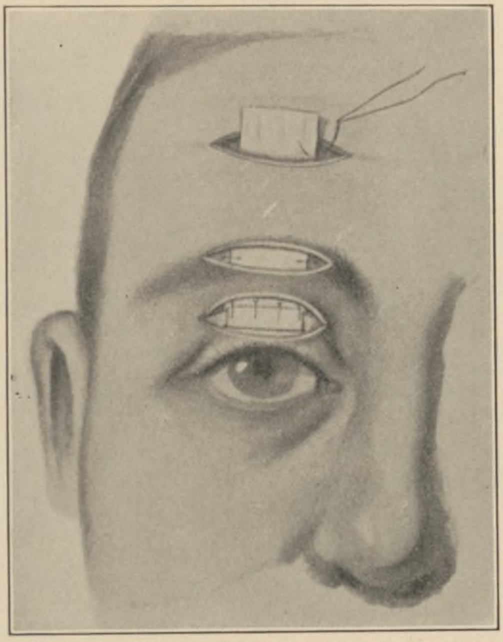

FIG. 38.—THE TECHNIC OF THE FASCIAL GRAFT IN THE OPERATIVE TREATMENT OF PTOSIS (Kirschner).

efforts at contraction, the muscle made a sharply angular prominence under the skin. The scar tissue was excised, the stretched tendon plaited, and a sheet of fascia enveloping the tendon and the belly of the muscle was sutured in place to bridge the defect. The result was excellent as to function as well as appearance.

Fascial grafts have also been used to give support that was lost by paralysis of single muscles or groups of muscles. Here the principle is, of course, not the transmitting of muscle contraction but the fixation of parts.

One of the groups of cases in which excellent results have been obtained is ptosis of the upper eyelid. Fascia is used instead of foreign material (silk) in the type of operation that has commonly been employed. Three short transverse incisions are made, one exposing the frontalis muscle, one over the eyebrow, and the third down to the tarsus. The skin is undermined between the incisions and a strip of fascia is sutured to muscle and to tarsus so that the lid is drawn up to the necessary extent. The precaution should be taken to avoid any overcorrection because the replacing fibrous tissue may contract slightly and an abnormally wide palpebral aperture will result. One would, therefore, be on the safe side by not completely correcting the droop of the lid. The transplant is fixed to the subcutaneous tissues at the eyebrow incision and the three wounds are closed.

Fascial strips have also been successfully used for the correction of the deformity accompanying facial paralysis. The outcome of nerve anastomosis or of muscle transference is uncertain and associated

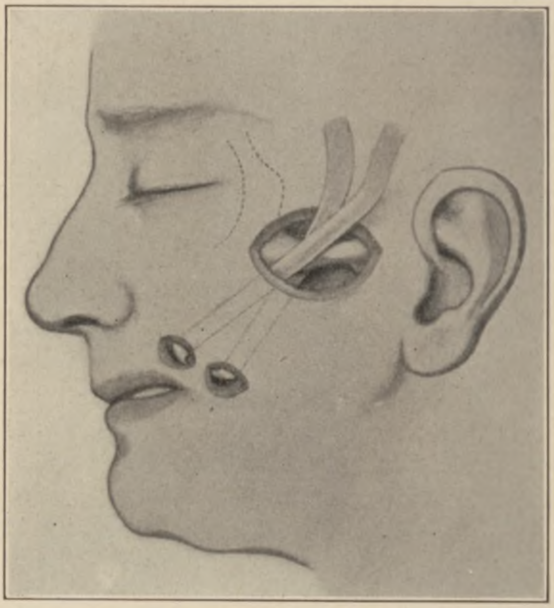

FIG. 39.—THE TECHNIC OF IMPLANTATION OF THE FASCIAL SLING FOR FACIAL PARALYSIS (Kirschner).

muscle movements are disturbing even in otherwise satisfying results in this operative treatment of facial paralysis. Kirschner suggested a simple operation involving permanent traction on the angle of the mouth and upper lip. The operation has been performed with excellent results. The method consists of making a transverse incision over the zygoma and two small incisions in the nasolabial fold. A strip of fascia lata of the required length having been detached, it is drawn through a subcutaneous tunnel made between one of these incisions and that over the zygoma. It is passed under the skin between the two nasolabial incisions and then upwards through another subcutaneous tunnel to the zygoma. Thus the two ends of the fascial ring come out at the upper incision and the strip makes a loop through the tissues of the cheek at the nasolabial fold. The ends are drawn sufficiently taut to correct the deformity. The ends are then passed over the zygomatic arch and sutured together.

Paralysis of the serratus with resulting winged scapula offers an excellent field for the use of fascial transplantation, the normal function of the muscle groups being chiefly one of fixation of the scapula. Other operative procedures do not usually give satisfactory results and are much more complicated. In favor of fascial transplantation is the simplicity of the procedure and the fact that an unsatisfactory result does not interfere with other operations one may wish to employ at a later time. The application of the method consists in the use of a fascial ring. Two points of fixation are chosen, varying with the type of paralysis and deformity, and the ring is passed through or about

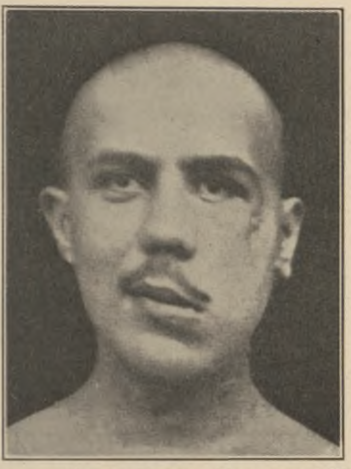

Fig. 40.—Total Facial Paralysis Due to Gunshot Wound (Burk).

Fig. 41.—The Result after a Fascial Graft in the Form of a Sling (Burk).

them. For example, an incision is made over the lower angle of the scapula and another over the eighth rib near its posterior angle, and the skin between the two points is tunneled. The scapula is perforated and the strip of fascia is passed through. The ends of the strip are drawn through the tunnel, passed about the rib subperiosteally, and are sutured together with the scapula held in the corrected position. Permanently satisfactory results, described at the end of one to two years, have been reported following this type of operation.

Only a few of the conditions have been mentioned in which fascial grafts have proved to be of value as muscle supports or substitutes for paralyzed muscles. They have been chosen as illustrating the usefulness of fascia for the purpose. Many similar types of lesions will undoubtedly lend themselves to correction in the same way. Isolated reports have already appeared. Thus Payr described a satisfactory result in a case of deltoid paralysis in which he sutured a broad sheet of fascia to a detached flap from the upper portion of the trapezius, spreading it over the joint surface and attaching it below to the long head of the biceps. In a case of congenital bilateral paralysis of the trapezius, Cramer used strips of fascia on both sides of the neck, extending from the cervical spinous processes to the upper inner angles of the scapulae. The functional as well as the cosmetic result was good. Many motor nerve injuries occurred in the recent war in which operations for nerve repair had to be deferred for months or indefinitely. In some of these cases, particularly in musculospiral and peroneal nerve injuries, fascial strips were used satisfactorily for the support of the drop-wrist or inverted foot. The procedure could be applied with equal success in some instances in civil life in which paralysis is permanent or when the return of function cannot be anticipated for a very long time.

Wider application should be made of this principle of fascial transplantation, for good clinical results can often be obtained in conditions otherwise not readily amenable to surgical treatment. The question of the time to begin motions after such transplantations is an important one. The time varies with the purpose for which the transplant was employed. Elimination of postoperative mobilization would make for firm fixation to the surrounding tissues, desirable in serratus paralysis, for example, but undesirable after an implantation into functioning muscle. In general, motions should be begun about a week after operation when a gliding movement of the transplant is desired, and immobilization should be continued for several weeks when the transplant has been used for fixation.

FASCIAL TRANSPLANTATION FOR DEFECTS IN AND ABOUT BODY CAVITIES

Dural Defects.—The use of fascial grafts for this purpose has apparently had wider clinical application than for any other single surgical condition, with the possible exception of hernia. More than a hundred cases have been reported in which fascia lata has been employed for the repair of dural defects. A careful analysis of the experimental and clinical basis upon which the procedure is to be advocated in surgery is therefore desirable.

At the outset, it may be said that there are those who hold that the repair of a dural defect is never indicated, adequate covering for the underlying pia-arachnoid and brain being given by the aponeurosis (galea) and skin. Unquestionably this holds true in some instances, but it is difficult to see how such a viewpoint can be correct for all cases. A detailed discussion of the various reasons for plastic repair of dural defects would lead too far afield. They may be stated briefly as follows: to offer support to the brain in cases of increased intracranial pressure where dura must be sacrificed at operation and other adequate support, such as muscle in subtemporal operations, etc., is not obtainable; as a substitute for dura that has been sacrificed at operation when the overlying segment of skull must be sacrificed as well; to control leakage of cerebrospinal fluid; to prevent adhesions between the brain, covered or uncovered by pia-arachnoid, and the overlying tissues; to minimize the chances for a meningeal infection when infection is anticipated in operative incisions or traumatic wounds of the overlying soft parts.

The question is whether or not these purposes can be fulfilled by any method of plastic repair. It should be stated at once that a simple incision and closure of the dura may be followed by adhesions. This being true, it is impossible to conceive of the elimination of adhesions as the result of an implantation of the same or any other tissue. A commonly employed method of plastic repair for small dural defects consists in splitting the adjacent dura into its two layers and turning down a flap of the outer layer to bridge the gap. This is a procedure of proved value, but here, too. adhesions to the underlying brain have followed.

Although there is no known way of preventing the formation of adhesions, an acceptable method of replacement of dural defects must minimize the chances for their development. Therefore the use of nonabsorbable foreign bodies, such as Cargile membrane, should not be considered. Homoplastic and heteroplastic tissues may act as irritating foreign bodies (see Chapter I). Because of this, as well as the likelihood of an infection that may follow their extrusion, foreign grafts are not desirable implants for the repair of dural defects. The statement holds true despite some reports of satisfactory clinical results following grafting of homotransplants of peritoneum (see Chapter III).

This leads to a consideration of the autografts that are available for the purpose. The ideal would, of course, be a tissue lined by endothelial cells that remained permanently viable when transplanted. Peritoneum and opened blood vessels have been suggested. From what is known of the fate of transplanted tissues (see Chapter I), there is no reason to believe that such grafts would remain viable; in fact, there is every reason to believe that the delicate endothelial cells would be among the first to die. That the dural endothelium tends to cover an adaptable transplant rapidly, will be subsequently shown. One can only conclude that the claims for persistence of the endothelial cells of peritoneal or vascular grafts are based on the erroneous assumption that the cells are the original ones and not the overgrown dural endothelium. From the viewpoint of practicability, autografts of peritoneum or of blood-vessels are not to be thought of, since the peritoneal cavity must be opened or blood-vessels sacrificed to obtain them.

Fat, fascia, and periosteum are the three tissues that are worthy of consideration, and all three have been used in clinical surgery as well as in experiments. A tissue replacing the dura should resemble that membrane as closely as possible, and in this respect fascia is the tissue of choice. Concerning the use of periosteum, large sections cannot be obtained without undue exposure of bone, and the removal of even small portions is not always a harmless procedure. Periosteum is not as readily handled, as resistant, nor as smooth as fascia. Adhesions between periosteum and brain were uniformly present in one series of experiments that has been reported. Reference has been made to the use of fat transplants for filling defects of brain surfaces (see Chapter III). Fat is not to be compared with fascia for the repair of dural defects because it lacks the resistance and ready adaptability to the margins of the defect that fascia offers. An objection to fat transplants for dural defects is the necessary thickness that is required, ultimately resulting in a correspondingly thick mass of replacing tissue as a possible source of irritation to the adjacent brain surface. Even those who are enthusiastic about the use of fat transplants in brain surgery concede the superiority of fascial transplants for dural defects, when the underlying brain surface is only slightly involved.

Of all the tissues proposed for implantation, fascia most nearly approaches the ideal. The results of experimental work prove conclusively that it heals well in place, makes water-tight closure, and does not subsequently act as an irritant. The claim for freedom from adhesions, originally made by Kirschner, is not warranted. In ten experiments von Saar noted widespread adhesions in three cases, a few adhesions in four, and their absence in the remainder. We have made similar observations. The claim for persistence of the transplant as such is likewise unjustifiable. The graft becomes very slowly and very gradually replaced by a fibrous tissue that closely resembles it. Little, if any, contraction of the replacing tissue is to be observed. Fusion between fascia and adjacent dura becomes complete at an early date. I have noted extension of endothelial cells over the inner surface of the graft at the end of two months.

Replacement of defects of the spinal dura were first carried out in some experiments I conducted. It was shown that the results were analogous to those noted above except for the fact that adhesions to the spinal cord or its membranes were not observed.

The results of fascial transplantation for dural defects in the human being follow closely those that have been noted in experimental work. The same very slow and very gradual replacement by fibrous tissue has been observed. Of the many cases that have been reported, there are only two in which leakage of cerebrospinal fluid occurred, and, in these, other complications that developed after operation were probably the cause. In not a single case in tbe literature can the graft be held accountable for sequelae that developed. It is ridiculous to make a fascial graft responsible for a continuation of epileptic seizures after operation; the usual outlook after removal of an adherent dural scar without any dural plastic is unfortunately only too well known. To attribute epilepsy, occurring after fascial transplantation at operations for craniodural or craniocerebrodural injuries, to the graft is unfair, unless the graft is found to have been converted into thickened scar tissue. In this connection I have reported the appearance of the grafted areas as seen one or more years after fascial transplantation for dural defects complicating cranial war wounds. At later operations, performed for the repair of cranial defects, the grafts were found to be identical in appearance with and undistinguishable from the adjacent dura.

FIG. 42.—TWO MONTHS AFTER FASCIAL TRANSPLANT INTO DEFECT OF SPINAL DURA.

A, dura continuous with the thickened and greatly altered transplant. *B*, *C*, smooth free surface of transplant. *D*, silk suture at margin of defect. *E*, *E*, *E*, the spinal musculature, fused with the deep surface of the transplant.

In view of the results that have been obtained, the indications for fascial transplantation should be extended to include any large dural defect, whenever a dural replacement is thought to be desirable. In the surgery of brain neoplasms, this includes varied lesions in which the sacrifice of large sections of dura is inevitable. It does not, of course, include instances in which dura is removed for the purpose of decompression.

Fascial transplantation has a special indication in the compound fractures of the skull with extensive dural involvement, occasionally seen in civil practice. Here the particular purpose is to afford a covering for the brain in order to aid in excluding meningeal or cerebral infection. There have been a number of cases under our care in which the procedure proved of great value. In one instance the transplant healed in place despite its exposure following infection and separation of the scalp. This case is of sufficient interest to be described:

The wound was grossly soiled. Débridement was practiced. The contaminated and soiled margins of the dura were carefully trimmed. Suture of the dura being impossible, a fascial graft about 5 by 5 cm. was implanted. Three days after operation, infection in the wound was apparent. Some sutures were removed to provide for drainage. The transplant lay exposed over half its extent for days until it was finally covered by granulation tissue and skin. In the subsequent course there were no signs of irritation or other symptoms referable to the retained graft.

Cranial injuries in the World War provided many cases in which I believed fascial transplantation was applicable, yet it appears to have been practiced only to a limited degree. The probable reason for this is that the correct treatment of these wounds was not appreciated until toward the end of the war. It would naturally have been foolhardy to have attempted repair of dural defects in the presence of infection. Primary union of the wound following operations for craniocerebral lesions occurred with uniformity only after the principles of débridement were applied to head injuries. It was only then that such refinements of technic as fascial grafting could be safely practiced. In my experience, fascial transplants were found desirable for closure of the dural defects in a number of cases, and the results have been most satisfactory. I have been in touch with these patients since the close of the war and can say that untoward after effects referable to the transplant have not appeared. Adhesions undoubtedly exist between the graft (or its replacing fibrous tissue) and the adjacent wounded brain area in some of these cases. The grafts, however, have not changed into masses of scar tissue. The best evidence is, as already noted, their appearance as seen at subsequent operations for the repair of skull defects.

Turning to the application of fascial transplantation for defects of the spinal dura, the desirability of closure of the dura, after it has been opened at spinal operations, is now generally recognized. Conditions arise in which it is impossible to suture the dura or in which suture would result in compression of the cord. The problem of repair of the gap left under such circumstances has not received the attention it deserves. Apparently surgeons have been content with leaving the dura open or with the implantation of some foreign, nonabsorbable material. I have demonstrated experimentally the advantages of fascial transplantation for large defects of the spinal dura and have reported the application of the method in clinical surgery. Since that time, other cases have come under my care in which the procedure has proved of value in the treatment of dural gaps too large for safe closure. An advantage in transplanting fascia in this field lies in the fact that fascia lata need not be employed, the aponeurosis overlying the erector spinae and exposed in the ordinary operative steps being available for the purpose.

The technic of fascial transplantation for dural defects does not require detailed description, since it corresponds in the main with that already described. Hemostasis before the graft is applied is, of course, essential, yet we have seen, in a few instances, cerebral wounds in which the outcome was satisfactory despite oozing at the time of implantation. We believe that edge-to-edge approximation between the margin of the transplant and that of the dura is more imperative in the transplantation of fascia into dural defects than in any other field, with the possible exception of pleural and bladder defects. In addition to the advantages that have been noted in wound repair, leakage of cerebrospinal fluid is best prevented in this way. Very fine needles should be used for suturing and small-sized silk makes the best suture material. Snug and accurate fitting of the transplant is essential for a satisfactory result. The best way to be assured of this is to inspect the field after the continuous sutures have been passed between three of the fixation points. The fourth fixation point is then shifted, if necessary, for the ablation of any excess portion of the graft.

Pleural Defects.—The absolute necessity for air-tight closure after operations invading the uninfected and free pleural cavity is universally recognized at the present time. There is no difficulty in securing closure by ordinary methods in the cases that are usually encountered. It is occasionally necessary to fashion musculocutaneous flaps for the purpose. When, however, large sections of the thoracic wall are to be removed, as for neoplasms involving several ribs, such simple procedures do not provide assurance against the dangers of air leakage and pleural infection. Furthermore, flapping motions of the overlying skin synchronous with respiration may occur and postoperative hernia of the lung may be anticipated. To obtain the necessary support, pedicled flaps including ribs adjacent to the defect have been suggested. Others have sutured the lung into the margins of the defect. The former measure is complicated and adds considerably to the extensive operative procedures involved in removal of the tumor; the latter manifestly can have no general appeal.

Both clinically and experimentally, fascial transplantation has proved an exceedingly simple step that adequately assures air-tight closure and the prevention of hernia. The first and most complete experimental work in this field was done by Kornew, who replaced large pleural defects with fascia. The replacing connective tissue, referred to as the original transplant, in and about the graft, permanently prevented herniation of the lung. Although Kornew rarely observed adhesion of the lung to the graft, others noted its occurrence. In order to prevent leakage the fascia was sutured *over* the defect.

In our experiments, two advantages were seen in suturing the transplant *into* the pleural defect. First, the ends of the resected ribs are not exposed intrapleurally, and, secondly, friction between the rib ends and the transplant is eliminated. We noted that the transplanted fascia soon lost its characteristic structure and that replacement phenomena began at an early date. Furthermore, overgrowth by pleural endothelium was seen to occur wherever the visceral pleura did not become adherent to the transplant. From the viewpoint of function, the results of the experiments were satisfactory.

FIG. 43.—FIVE MONTHS AFTER FASCIAL GRAFT FOR A PLEUROTHORACIC DEFECT.

A, *A*, the two layers of altered fascia bridging the defect. *B*, *B*, parietal pleura with layer of cells covering the free surface except at the adhesion of lung. *C*, *D*, so-called thickened pleura. *E*, villous projection from the newly formed pleura. *F*, *F*, subcutaneous tissue.

Very few clinical cases have been reported in which fascia has been used for the closure of pleural defects. The first was made by Payr, who described the case of a patient suffering from a chondrosarcoma of the chest wall involving the ribs. It was necessary to sacrifice the pleura as well as the chest wall in removing the tumor and the large defect was covered by a fascial transplant. Six months later a recurrence of the growth was found. The chest wall was solid, although somewhat retracted over the defect, and barely moved with respiratory efforts. Another similar case was reported by Payr. Kornew described two cases, one a hernia of the lung satisfactorily treated by fascial transplantation.

The procedure would appear to be ideally suited for large pleural defects, yet the number of reported cases is too small for final decision as to its value. In the following case in my experience, a perfect result was obtained under circumstances that almost excluded the application of any other method:

A thin woman, fifty years old, presented a recurrent carcinoma of the chest wall at the inner end of the scar ten years after a radical amputation of the breast for carcinoma. The overlying skin was involved and the sessile neoplasm invaded the second and third ribs and intercostal tissues near the costochondral junction. At operation under intrapharyngeal anesthesia, the involved ribs were divided laterally to the tumor and the parietal pleura was found to be adherent to the growth. The free pleural cavity was, therefore, entered and the chest wall freely sacrificed about the neoplasm. The internal mammary vessels were secured above and below, and the removal of the portion of the chest wall bearing the tumor completed by carrying the dissec-

FIG. 44.—SARCOMA OF THE CHEST WALL (Kirschner).

tion through the second and third rib cartilages. A sheet of fascia lata, 8 by 8 cm., was sutured into the defect, being attached to the pleural margin with the usual technic. As the last sutures were placed, increased intrapharyngeal pressure was used to bring the lung up to the surface. A wet compress was then placed over the transplant to control any air leakage that might occur and the skin was mobilized sufficiently for closure. The compress was removed and the skin promptly approximated and sutured over the transplant. There was no air leakage and no pneumothorax after operation; the physical examination made to determine this was confirmed by a series of postoperative X-ray pictures. It is now two years since operation. Massive X-ray therapy has been administered. The patient has gained greatly in weight and strength. The defect is bridged by a solid membrane that does not bulge in the least upon coughing or straining. Physical and X-ray examinations present no evidence of pleural or pulmonary adhesions in the operated area.

Defects of the Abdominal Wall.—Many experimental studies have established the evidence that fascial transplants effectively prevent the development of hernia after sacrifice of various layers of the abdominal wall. The rectus sheath was replaced by fascia lata in one group of experiments. In another series, aponeurosis and muscle were successfully replaced; the peritoneum, transversalis fascia and muscle, in a third series. Finally, all the layers of parts of the abdominal wall, ex-

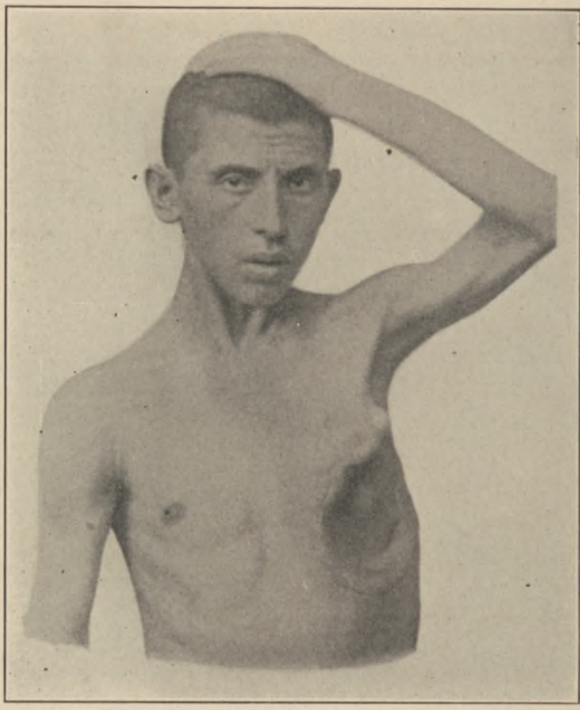

FIG. 45.—RESULT AFTER RESECTION AND FASCIAL GRAFT FOR THE PLEURAL DEFECT (Kirschner).

clusive of skin, have been replaced by sheets of fascia and hernias did not ensue.

The methods that are ordinarily employed in the effort to cure large hernias need not be enumerated. All are agreed that they not infrequently fail when wide herniation exists and the tissues about the defect offer little possibility for adequate repair. The necessity for some form of implantation to bridge the gap under these conditions was realized many years before the advent of free tissue transplantation. This was the era of metal and celluloid plates, silver filigree, etc. With the evolution of tissue grafting, a variety of tissues was employed for the same purpose, periosteum being most widely used. No clear proof of their value has appeared. The remarkably uniform results of experimental fascial transplantation naturally led to a widespread use of fascia at operations for all varieties of hernia.

It would appear that a sufficient number of years has elapsed since fascial transplants were first employed (1909) to permit a definite evaluation of the method in the surgical treatment of hernia. Unfortunately, however, but few precise statements can as yet be made. The reason for this is a simple one. Almost without exception, reports in the literature would lead to very enthusiastic conclusions, but they nearly all deal with the immediate or early results of operation. That reports of cure after hernioplasty are premature, if made before two or more

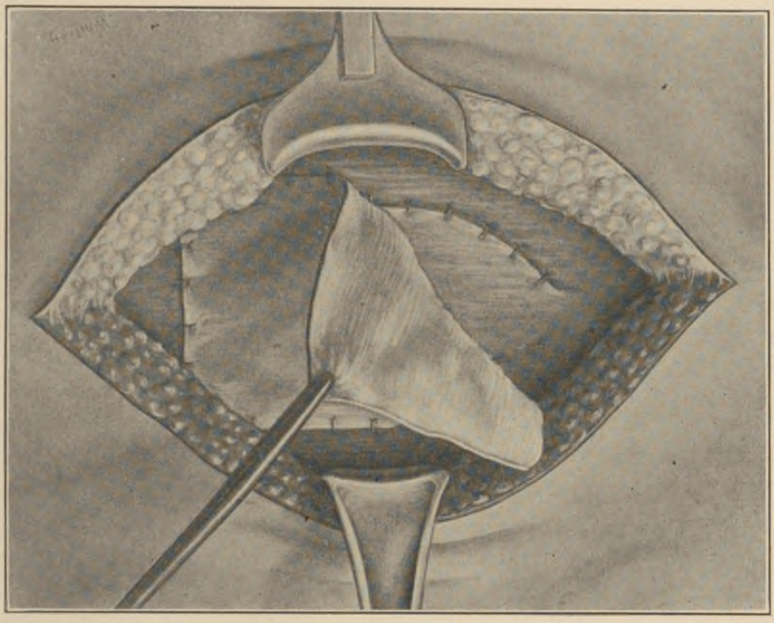

FIG. 46.—SHOWING THE METHOD OF REINFORCING THE MAYO VENTRAL HERNIA OPERATION BY A FASCIAL GRAFT (Law).

years have elapsed, is common knowledge. Yet this fact has not been considered to any extent in reports of cases, usually difficult of cure, that have been subjected to fascial grafting. All that can be said at the present time is that the evidence clearly indicates that fascial transplantation is of great value as an aid to cure by hernioplasty, when hernioplasty alone would give doubtful results. There is less evidence to indicate that the application of the method may be considered curative in the absence of plastic repair of the abdominal parietes, although a few remarkable cases have been described.

The principles involved in the use of fascial transplants for the reinforcement of hernioplasty are simple. The graft is sutured in place under moderate tension in order to share the strain on the underlying suture line directly after operation. Broad sheets of fascia are required because reinforcement of a doubtful suture line is best attained by wide contact between the graft and the tissues beneath it. The repair of a hernia usually entails the placing of sutures and the approximation of tissues in the lines of greatest force. If a small gap subsequently appears, the tendency is to an ever-increasing size of the recurrence. A fascial transplant will aid in giving a new direction to the lines of strain by taking up some of the tension, and thus aid in minimizing the extent of a recurrence.

The most important indication for using fascial grafts is a scarcity of satisfactory tissue about the hernial gap. Tissues that do not lend themselves to adequate repair cannot be expected to withstand the great strain that will be put upon them, particularly when they have been approximated under tension. Such a situation is often characteristic of recurrent hernia, of large direct hernia, or of hernia following infected abdominal wounds. These are the fields in which the transplantation of fascia is especially applicable.

Inguinal Hernia.—Only in the exceptional cases is fascial transplantation indicated. It has been learned in recent years that the presence of healthy, well-developed musculature is not essential for the radical cure of inguinal hernia. That a cure can be attained in many cases in which the "conjoined tendon" is poorly developed is now common knowledge. This condition of affairs should therefore not be made the excuse for an unnecessary fascial transplantation. Good approximation between the aponeurosis of the external oblique and Poupart's ligament usually suffices. Conditions are often different, however, in large, direct, and in some of the recurrent indirect, inguinal hernias that are encountered. It is under such circumstances that fascial grafts can be profitably employed. The technic of transplantation is simple. After the tissues are mobilized for approximation and the sutures are placed, one margin of the graft is attached to the reflected surface of Poupart's ligament. It is firmly anchored for the full length of the inguinal canal. The sutures placed for the ordinary approximation are tied. The graft is then sutured, under some tension, to the surface of the internal oblique muscle. The method of splitting the fascia to allow for transplantation of the cord should be mentioned, for it appears to be the one that has usually been employed. It does not appeal to us, however, for the transplant is weakened thereby and its chief value is endangered. Except in direct hernia, we have not transplanted the cord. The transplant is sutured over the cord and then the cut margin of the external oblique aponeurosis is approximated to Poupart's ligament.

The late results in seven cases may be given at the present time, the interval since operation ranging from two to five years. All have remained free from recurrence. In several instances of recurrent inguinal hernia, an orchidectomy was added to make possible a complete and tight closure of the inguinal canal. Of the seven cases, fascial grafts were used for reinforcement of sutured cicatricial tissues in five. The remaining two cases were large, recurring, direct hernias and the fascial transplant was used to bridge the gap, plastic closure not being feasible. These latter cases offer the best evidence of the efficacy of fascial grafts in operations for inguinal hernia.

Femoral Hernia.—This has had a wider application of fascial grafts than inguinal hernia. One method is the implantation of a strip of fascia throughout the length of the femoral canal with resulting occlusion. Another procedure consists in the use of a sheet of fascia sutured in place above the canal. Satisfactory results have been reported by the use of these methods. They may possibly be applicable in very exceptional cases, but, as a rule, there should be no indication for any free tissue transplantation in the operative treatment of femoral hernia.

Umbilical Hernia.—The usual methods of plastic repair suffice in most cases. Occasionally, however, lesions are encountered in which closure of the defect by one of the ordinarily employed methods is manifestly unsatisfactory and recurrence is to be anticipated. A favorable situation for fascial transplantation exists under such circumstances, the graft acting as a reinforcement to the suture line.

It is well known that operations for umbilical hernia are attended by fairly high mortality. This is in part due to the obesity and the generally poor physical condition of many of these patients. The mortality is probably referable in part, however, to the reposition into the abdominal cavity of the contents of the sac and the reduction in the size of the abdominal cavity by the usual methods of plastic closure, and these methods are, therefore, occasionally fraught with danger. We believe that the closure of large gaps, by the usual procedure of overlapping, is not always indicated, and here an indication for fascial transplantation may exist, that is, for the purpose of bridging the defect.

My experience is limited to two cases that were almost identical. The patients were poorly nourished old women with irreducible umbilical hernias containing omentum, transverse colon, and loops of small intestine. Being serious surgical risks, local anesthesia was employed and minimal operative procedures were imperative. Adherent omentum was resected and the hernial contents were reduced in the usual way. Repair of the defect would have meant extensive plastic work carried out on ill-nourished tissues. In each case, a large sheet of fascia lata was sutured in place under moderate tension after the fibrous border of the hernial ring was excised. The skin was closed without drainage. Thus fascia was the only membrane between abdominal contents and skin over an area about 5 by 7 cm. Although several years have elapsed since operation, both patients are as yet free from recurrence.

Postoperative Ventral Hernia.—In this field, too, the ordinary operative measures usually suffice. There is a group of cases, however, in which extensive scar tissue, frequently the result of repeated efforts to cure a postoperative hernia after an infected wound, does not permit the ready approximation of healthy aponeurotic layers. In these cases, fascial grafts should prove of great value for reinforcement. A number of cases have been reported of permanent cures obtained by the use of grafts, when in all probability failure would have followed the usually employed operations. Among them are a few instances in which the graft healed in place despite the presence of fistulae at the time of operation, with subsequent infection of the wound and exposure of the transplanted fascia. There are as well a few instances in which approximation of the aponeurosis of the abdominal wall was not obtained and fascial grafts were successfully used to bridge the defects.

In my own experience, fascial transplants were used for postoperative ventral hernia in four cases. All but one had been subjected to previous operations for the repair of the hernia. In two that followed appendicitis operations, all the layers of the abdominal wall were readily approximated except the anterior rectus sheath. The latter could only be sutured under considerable tension. A satisfactory result appearing problematical under these circumstances, the suture line was reinforced with a fascial graft. Both patients have remained free from recurrence.

The third case is the only failure I have had with fascial transplantation for abdominal hernia and this may properly be considered as only a partial failure. Following cholecystectomy a large postoperative hernia appeared. Two previous operations for repair had not succeeded in effecting a cure. Serious postoperative pulmonary complications developed after both operations. At the operation, performed under local anesthesia, the widely separated margins of the triangular defect were exposed. One border was parallel and very close to the free costal margin, the other not far removed from the median line. A most extensive plastic operation would manifestly have been necessary to close the gap and it was questionable if even this would succeed in view of the situation of the hernia. I decided against opening the peritoneal cavity and attempting to approximate all the layers of the abdominal wall and limited the operation to defining and freshening the margins of the defect in the aponeurosis, and implanting a large sheet of fascia lata into the gap. The skin was sutured. A superficial infection at the lower angle of the wound supervened, and a small portion of the transplant was exposed for several weeks, but the fascia healed in place. More than a year has elapsed since operation. No herniation is visible on inspection or palpation, a resistant plaque of tissue occupying the operative field. Upon straining, however, there is a moderate, dome-shaped, bulging of the wound. Such a result can be classified fairly as a great improvement over the condition existing before operation, but not as a cure.

Defects of the Diaphragm.—The early experimental work in this field failed because the diaphragm was approached through abdominal incisions or because inflation of the lung was not practiced in thoracic exposures. Successful results during short periods of observation were obtained in later experiments. If fascial transplantation into diaphragmatic defects was to have any possible clinical application, it was, of course, essential to demonstrate that the tissue in the gap offered a lasting barrier to the development of a diaphragmatic hernia or eventration. This I was able to establish in a series of experiments. I found that the transplant became firmly fused with the diaphragm, and, albeit altered in histologic structure, was sufficiently resistant to prevent any protrusion of the abdominal contents. A striking feature of my experiments was the complete overgrowth of the large transplant by pleural endothelium on one side and peritoneal endothelium on the other.

Despite satisfactory experimental results, a clinical application of the method will be indicated only in unusual cases. It has been shown that large gaps in the diaphragm can be sutured without any great difficulty. The lateral thoracic attachments of the organ may be mobilized if necessary. Neighboring organs (stomach, liver, spleen, lung) have been used to plug the gap, but such procedures do not offer assurance of radical cure.

Given unhealthy musculature about the rent in the diaphragm, it is clear that simple approximation, particularly approximation under

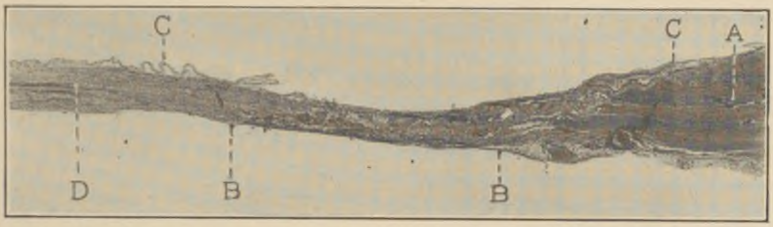

FIG. 47.—FIVE MONTHS AFTER FASCIAL TRANSPLANT INTO A DEFECT OF THE DIAPHRAGM. *A*, muscle of diaphragm at one margin of defect. *B*, *B*, layer of peritoneum (folded in the section). *C*, layer of pleura spread over the free surfaces of the transplant. *D*, altered fascia.

tension, does not assure a permanent closure. The value of fascia for the reinforcement of a doubtful suture line in the diaphragm is evident, yet the method does not appear to have been employed. I can describe two cases in which fascial grafts were used for this purpose with satisfactory results. The first was a thoracico-abdominal war wound involving diaphragm and liver. The massive missile lodged in the liver was removed through a thoracic approach. The large, irregular, jagged tear in the diaphragm was trimmed, but could not be sutured without tension. Another wound near the spine requiring treatment, a broad strip of the aponeurosis over the erector spinae was removed and implanted over the suture line in the diaphragm. The immediate result was satisfactory but the later course is unknown.

It was my privilege to be associated with Dr. Howard Lilienthal in his treatment of the second and more interesting case. The patient had had a crushing injury with a compound fracture of the lower ribs on the left side. A hernia of the stomach through the diaphragm ensued for which operation was imperative despite the presence of a large infected wound. A transthoracic incision was made and stomach, transverse colon and omentum were reduced into the abdominal cavity.

Omentum adherent to the rent in the diaphragm was detached. The large irregular gap in the left dome of the diaphragm was closed by a number of sutures. It was evident that the sutures did not hold well in the musculature. A large sheet of fascia lata was, therefore, added for reinforcement, being attached over the suture line with moderate tension. Thoracic drainage was necessary and the infected wound persisted for a number of weeks. Despite this fact, the transplant healed in place and the patient has remained free from recurrence. A year has elapsed since operation.

Pericardial Defects.—The problem of replacement of pericardial defects is but rarely encountered in clinical surgery. When the occasion arises,

Fig. 48.—Two Weeks after Fascial Transplant into a Pericardial Defect.

A, *A*, folded end of degenerating transplant, firmly united to cut margin of pericardium, *B*, *B*, *B*. *C*, silk suture at site of junction. *D*, smooth layer of tissue on free surface of transplant.

the restoration of the continuity of the sac is indicated. Suture of the parietal pericardium proving impossible or undesirable, various plastic procedures have been employed to fill the gap. Fascial transplantation would appear to offer a more rapid and efficacious method of repair. We initiated some experiments in which the immediate results were excellent, both anatomically and functionally, even when large defects were replaced. Firm union between fascia and parietal pericardium took place despite the little nourishment accessible to the graft and the degree of tension to which it was subjected. The inner surface of the fascia remained smooth and free from adhesions. It was impossible to determine the ultimate results, owing to the supervention of fatal pleural infections after operation.

Special Uses of Fascial Bands—*The Suspension of Organs.*—Fascial bands have been employed for purposes of fixation or suspension in the operative treatment of movable kidney, undescended testicle, and prolapse of the rectum, and satisfactory results have been described. The organs have been permanently held in the position attained at operation and to this extent the method may be called successful. We believe, however, that the principle involved in the use of fascia for such purposes is illogical, particularly in the case of undescended testicle and prolapse of the rectum. The latter condition can be adequately treated by other operative measures; furthermore, infection of a sheet of fascia placed about the rectum may have unfortunate sequelae. In orchidopexy, the basis of the operation should be a release of the testicle and cord so that the testicle lies in the scrotum without tension, and not a procedure involving traction to hold it in place.

The use of fascial grafts for suspension of the kidney is based on more logical grounds. The procedures that are ordinarily employed for the purpose fall into three groups: first, fixation by sutures including the fatty or fibrous capsule or the parenchyma as well; secondly, fixation by promoting broad fibrous adhesions about the kidney; finally, fixation by flaps from the capsule of the kidney or from the lumbar musculature. All these methods may result in damage to the kidney and the sequel is uncertain after plastic flap procedures. For this reason the use of fascial bands was suggested as offering a simpler and surer method of renal suspension.

Failures have not been reported after fascial suspension of the kidney and it may, therefore, be assumed that the various technical procedures have been successful. Cordua's method, in which a strip of fascia is passed beneath the fibrous capsule below the renal pelvis, may subsequently lead to compression of the pelvis, and is, therefore, not to be advocated. Kocher used a sheet of fascia to envelop the lower pole of the kidney and the ends of the graft were then secured to the lumbar fascia at an appropriate level. The simpler method described by Kirschner has sufficed for fixation in all the cases in which it has been employed and appears to be the method of choice. A broad strip of fascia is drawn through the fibrous capsule at the upper pole of the kidney, two incisions in the capsule being made for the purpose. The ends of the strip are passed about the twelfth rib, drawn upon sufficiently to bring the kidney to the desired position, and are then sutured together. The kidney is thus suspended from the last rib by a sling. Although the immediate aim of any of the methods of fascial grafting is suspension of the organ, it is evident that the end result is a fixation of the kidney in its new position.

Fascial Strips as Suture Material.—Experimental studies and clinical reports have demonstrated that fascia can be adequately employed for this purpose. The occasion for its use as a substitute for the usual suture material does not ordinarily arise, but strips of fascia have been successfully used in operations for the repair of fractures of the long bones and of the patella. No advantage of fascia over kangaroo tendon has been demonstrated, however, and the same statement holds true for the use we have made of fascial sutures in a few operations for hernia.

The use of fascial bands as substitutes for silk sutures to obtain more secure occlusion of the pylorus has been advocated, and experimental work has been reported in which tight closure of the pylorus was maintained by this means, whereas silk sutures were found to have failed. However, I demonstrated the inefficacy of pyloric occlusion by fascial bands and indicated at the time of my report that the periods of observation had been of too brief duration in the previous work done in this field. Prolonged pyloric closure cannot be assured by any known method of ligature. Enthusiastic clinical reports on the use of fascia for this purpose have appeared from various sources but seem based on the same inadequate periods of observation as in the experimental studies. Any type of ligature may occlude the pylorus for a time, although the results are always uncertain, and there is no reason to believe that fascial strips will prove an exception to this rule. A specific objection to the use of a fascial graft is the fact that adhesions from adjacent structures and perigastric induration may result as the transplant undergoes absorption and replacement.

Fascial Transplants in the Surgery of Joints.—The use of free transplants for interposition after operative measures employed in mobilizing stiff joints has already been discussed (see Chapter III). The question of using any living tissues for the purpose has been taken up and will only be touched upon here. If an interposing material is to be employed, there is no reason to believe that the same material and method will always meet the problem presented by the various situations. This statement can be safely made despite the ardent support that free fat transplantation has received from Lexer and others to the exclusion of all other grafts. Excellent results have been described after the use of pedicled flaps of fat, muscle, and fascia, and after free transplants of fat and fascia. In view of what has been said of the possibly disastrous fate of any free transplant even under ideal circumstances (see Chapter I), it should be clear that a free graft is not to be implanted into a joint unless such a procedure appears to be the only solution of the problem. An operation that might otherwise be successful in mobilizing a joint may prove a failure because a free graft has been inserted. If the incontrovertibility of this fact were kept constantly in mind, much more limited use would be made of free grafts into joints. A pedicled graft of fat, fascia, or muscle may almost invariably be obtained from the neighborhood of a joint and such a procedure is preferable if any interposing tissue is to be employed.

Our knowledge of the fate of free fascial grafts into joints is best derived from experimental studies that have been made. The phenomena appear to be almost identical, whether fascia, fat, or muscle, or other tissues are implanted. The graft becomes changed into an undifferentiated connective tissue at a relatively early stage. There is an increase in size as compared with the original dimensions of the graft, and more or less complete encapsulation by a smooth layer of tissue occurs. The source of the latter, resembling a form of bursal covering, is not clearly understood. Its effect is to minimize the possibility of recurring adhesions with consequent fixation of the joint after operation.

The technic of fascial transplantation in the surgery of joints varies to such a degree according to the joint and to the part of the joint to be covered that no attempt at a detailed description will be made. The underlying principle is to cover any raw areas of bone or cartilage by sheets of fascia fixed to peripheral portions of the joint or outside the

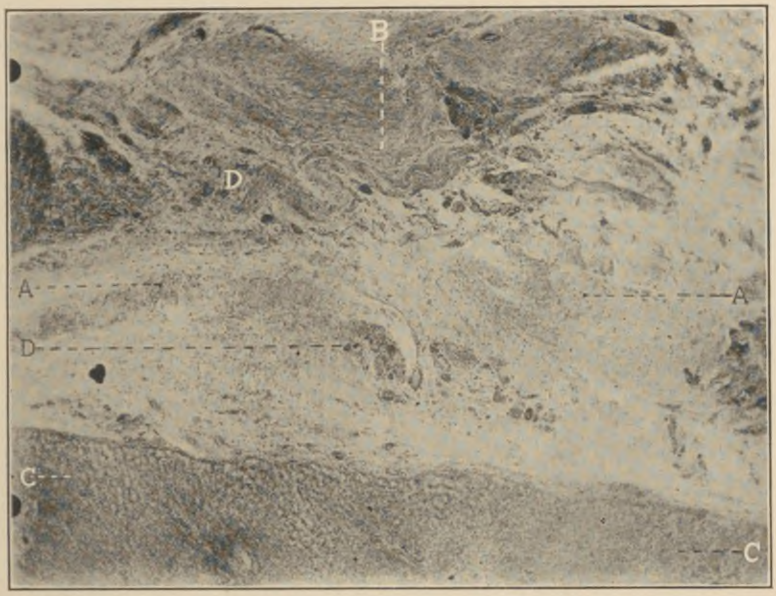

Fig. 49.—Six and One-half Months after Fascial Transplant into a Defect of the Surface of the Liver.

A, *A*, completely transformed fascia, recognizable as such in several places as at *B*. *C*, surface of liver, smooth and intimately connected with the transplant. *D*, *D*, islands of liver cells scattered in connective tissue.

joint proper. It is essential to suture the transplant in place in such a way that it will fit smoothly upon motion of the joint in any direction and to any degree.

Fascial Transplantation for Injuries of the Liver and of the Lung.—Free grafts of fat as well as of fascia have been used for the double purpose of controlling bleeding from, and covering the defects in, these organs. The double problem is encountered at operations involving resection of portions of the organs or as the result of crushing injuries or penetrating wounds. The use of fat for the purpose has been discussed (see Chapter III). Comparing fat and fascia for the treatment of the lesions in question, fat has the probable advantage of a more potent hemostatic action and fits interstices and depressions much more readily. It does not hold sutures as well as fascia and does not offer as smooth and flat a covering. The greatest advantage in the use of fascia is its capacity for withstanding tension. Fat or fascia will, therefore, be chosen according to the indications that exist.

Excision of tumors and closure of wounds of the liver have been made feasible by improved methods of suturing. It has been found, however, that the tendency for sutures to cut through cannot be eliminated, especially when the liver substance is friable. The newer suture methods have been of little aid in the problem of obliterating large flat defects of the liver. Tamponade, always an objectionable feature, is accordingly necessary in many instances after operations on the liver. The purpose in using transplants is a threefold one: to permit closure of the abdominal wound without packings; to eliminate the danger of hemorrhage after removal of the tampon; and to utilize the hemostatic action of living tissue.

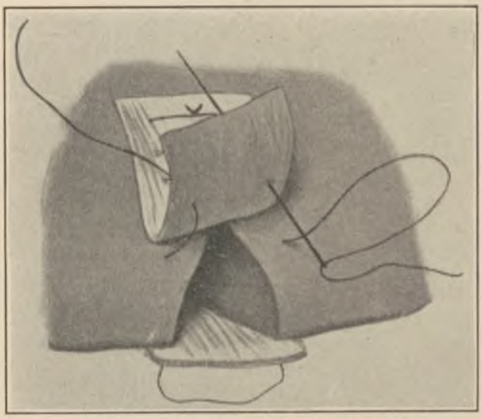

Fig. 50.—Suture of a Wedge-shaped Wound of the Liver with Fascial Reinforcement (Kirschner).

Before fascial grafts could be used clinically it was necessary to learn what would happen after they were sutured over or into defects of the liver. Experiments performed previous to our own demonstrated that the immediate results of fascial grafting were satisfactory. Our experiments showed that the transplant remained adherent to the site of the raw area in the liver after a period of six and a half months, a close fusion occurring.

The number of cases in which the method has been applied in clinical surgery is small but the results are impressive. Large wounds and large raw areas left by resection have been adequately treated in this way. Various methods of transplanting fascia for wounds of the liver have been described. The choice depends largely upon the type of defect that is encountered. In resection of portions of the liver that include the free border, fascial strips can be placed upon the upper and lower surfaces about the area to be resected and mattress sutures passed between them through the substance of the organ, and tied. A hemostatic ring is thus made. In a resection resulting in a V-shaped defect, the margins can be drawn together by approximating the fascial strips. In suturing wounds of the liver with the help of fascia, the simplest method is to place a strip along each lip of the wound and to pass sutures through one strip into the depths of the liver substance about the tear, and out through the strip on the opposite side.

As far as we are aware, the fascial graft has not had any clinical application for the repair of injuries to the lung, fat having been used

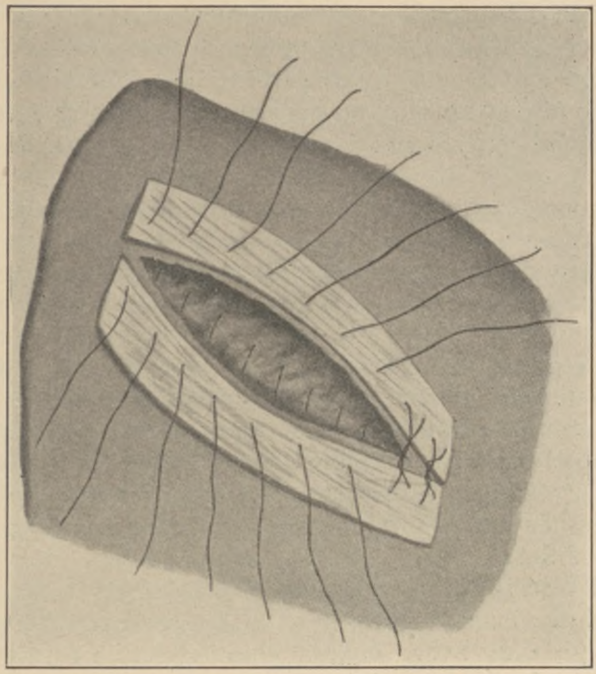

Fig. 51.—Suture of a Superficial Wound of the Liver with Supporting Strips of Fascia (Kirschner).

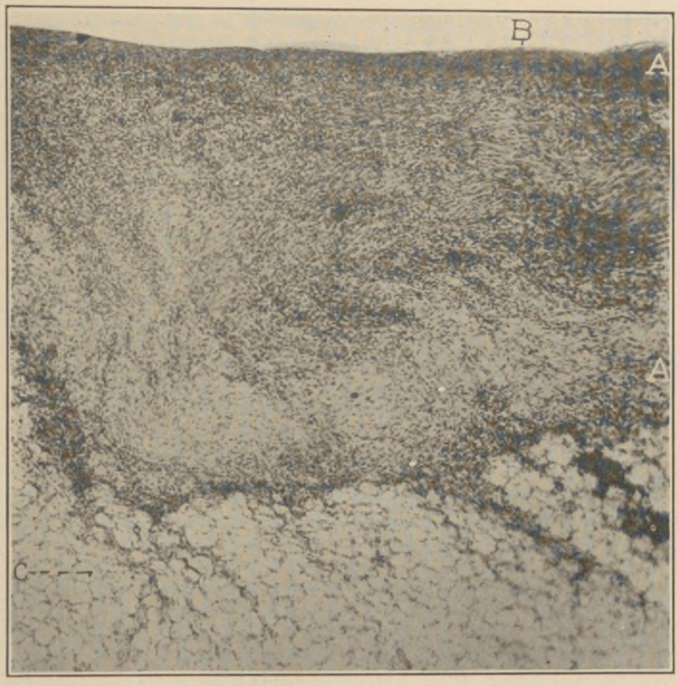

Fig. 52.—Two Weeks after Fascial Transplant over Defect of Lung. *A*, the transplant undergoing degeneration. *B*, smooth free surface of graft. *C*, lung.

exclusively when a transplant was thought necessary. Our own experimental work, as well as that performed by others, indicates that fascial transplants might prove of value for the closure of pulmonary fistulae or for covering raw or bleeding areas encountered at operation. On the basis of successful experimental work, the suggestion has been made that sheets of fascia might be used to maintain collapse of pulmonary lobes and that small caps of fascia over stumps of bronchi might secure air-tight closure.

Fascial Grafts in Operations on Nerves.—This application of fascial transplantation is worthy of only passing mention, despite the fact that the method has been freely used in operations for the repair of nerve injuries. Undergoing replacement phenomena, the transplant can but add to the amount of fibrous tissue surrounding a nerve anastomosis. The only difference we can see is that the graft becomes adherent to the nerve instead of to the surrounding tissues. The result is a persisting, tough fibrous envelope. Were the graft not present, any adhesions to surrounding tissues would probably be less dense and tend to disappear in the course of time.

The use of fascial tubes to bridge nerve defects has no established value. They have been employed with the idea of acting as conduits for the newly growing nerve fibers. The inevitable result is additional fibrous tissue to be traversed in the process of nerve regeneration. Other forms of tubulization have yielded better results (see Chapter V).

Fascial Grafts for the Repair of Defects of the Main Arteries—*Traumatic or False Aneurysms.*—The use of strips of fascia for the reinforcement of doubtful suture lines in blood-vessel anastomoses has been suggested but seems to have no real value in clinical application. An anastomosis must be adequate to begin with, if a satisfactory outcome is to be expected. A method of enveloping fusiform aneurysms of the aorta by sheets of fascia has also been proposed with the idea of resisting further increase in size. Halsted has shown that strips of fascia wound spirally around the aorta maintain compression for a time (two months) with subsequent gradual return of the lumen to its previous size. He believed that such a procedure might suffice to cure an aneurysm distal to the site of constriction. Possible applications of this and other methods of fascial transplantation in the treatment of aneurysms lie in the future.

A method of fascial transplantation in vascular surgery that has proved of undoubted clinical value in my hands is the grafting of fascial patches into lateral defects of the popliteal artery, in the treatment of traumatic aneurysms, the result of gunshot wounds of that vessel. My clinical work was directly based on an experimental study of the question. The latter may therefore be presented. The implantation of a section of an artery or vein is the best procedure for replacing an arterial defect. In the same way, a patch of arterial wall has been described by Carrel as the ideal method of substitution for lateral defects of arteries (see Chapter VII). Subsequently he investigated, in two experiments, the surgical possibilities in the use of a patch consisting of peritoneum and adjacent musculature. He reported that "the adaptation of the peritoneal patch to the aortic wall was so perfect that the vessel, less than two years after the operation, was absolutely normal. Although the new wall was composed of tissues different from normal, the morphology of the aorta was not modified." This, then, is a demonstration that a small lateral defect of an artery can be satisfactorily replaced by a transplant other than a vessel wall but simulating arterial structure in the smooth peritoneal lining on one side and the attached muscle on the other.

The purpose of my investigations was to demonstrate that fascia is as serviceable as vessel wall or peritoneum with muscle for the replacement of even large lateral defects of the main arteries, and to show that the method has greater possibilities for clinical application in appropriate situations encountered in clinical surgery.

Except in the hands of a master of the technic of blood-vessel surgery, a simple, end-to-end suture of a divided vessel has resulted in failure in many of the experimental attempts. The special technic required for the various steps of this operation will be detailed elsewhere (see Chapter VII). In patching an arterial defect with a section of artery or vein or peritoneum-muscle, the same accurate apposition of intima of vessel to intima or endothelium of transplant, is essential, avoidance of any trauma to the inner lining of the transplant is necessary, and special suture material must be used. In short, the same painstaking technic as that for end-to-end suture of an artery must be carried out to ensure any measure of success. The operation being more complicated and the use of a transplant being involved, an even higher percentage of failures may be anticipated.

From the reports of microscopic examinations of transplants of vessels showing gradual conversion into fibrous tissue, it appeared to me that it was not imperative to employ like (artery, vein) or even morphologically similar (peritoneum-muscle) tissues to adequately replace lateral arterial defects. Indeed, I believed that, theoretically, a simple, strong connective tissue (fascia) would offer several advantages, for it could be used without fear of damaging a delicate intima and without the necessity of absolutely accurate apposition of layers; in other words, without all the refinements of technic essential to the success of the other transplants. Apart from considerations of technic, the outlook for the success of a fascial graft was inherently greater than that of such highly differentiated tissues as artery or combined peritoneum and muscle.

Turning to the question of the possible clinical applicability of the various tissue grafts that have been employed for lateral arterial defects, it is clear that the surgical conditions involving their use will be almost invariably emergencies encountered by the general, and not the specially trained, blood-vessel surgeon. Autotransplants of portions of artery are manifestly not obtainable in human surgery and are, therefore, not to be considered. Vein grafts are more feasible. To obtain them, however, a separate wound exposure may be required, valuable time may be sacrificed for the careful dissection and proper preparation of the transplant (secondary hemorrhage and death followed in both instances in which they were used to patch the aorta), and the necessary ligation of a large venous trunk is never desirable and by no means always harmless. The abdomen would not be opened merely to obtain peritoneum-muscle transplants. Their applicability would, therefore, be sharply limited to lateral defects of intra-abdominal vessels and, as has been said, would involve special preparations and elaborate technic for their removal and successful transference. Autotransplants of fascia are accessible in the neighborhood of almost every operative wound. Fascia lata, however, because of its strength, smoothness, and consistency, is best suited for the purpose.

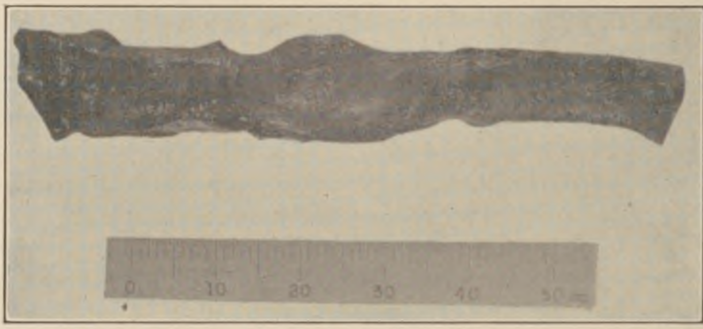

FIG. 53.—APPEARANCE OF A SPECIMEN OF A SUCCESSFUL FASCIAL GRAFT FOR A DEFECT OF THE THORACIC AORTA, SEVEN MONTHS AFTER OPERATION.

The patch lies between 13 and 40 on the millimeter scale. The apparent dilatation at the site of transplantation is the result of contraction of the adjacent arterial wall upon removal of the specimen.

To determine if a fascial transplant will fulfill the essential requirements of a tissue graft for a lateral arterial defect the following criteria are to be considered: The transplant should not act as a foreign body. There must be the minimal possibility for the development of thrombosis and occlusion. If the graft does not remain viable, the site of the defect must be occupied by a permanently resistant mass of connective tissue, smoothly lined on its inner surface, and not encroaching on the lumen of the vessel, thus preventing the possibility of aneurysmal dilatation. The replacement of large defects must be feasible, for small ones can be closed by simple suture. The technic and armamentarium involved in obtaining and implanting the graft must be simple to be universally applicable.

The results of the experiments proved that all these requirements were fulfilled by the use of fascial transplants. Seven experiments were performed on dogs, of which four were followed for sufficiently long periods to report the ultimate results. In only one—fascial replacement of a large defect of the abdominal aorta involving almost the entire circumference—did hemorrhage follow, and in this experiment total resection with end-to-end suture or tubulization by another vessel would have been more logical. Grafts were successfully implanted into large defects of the walls of the thoracic aorta, the abdominal aorta and the carotid and femoral arteries. In the examination of the specimens from

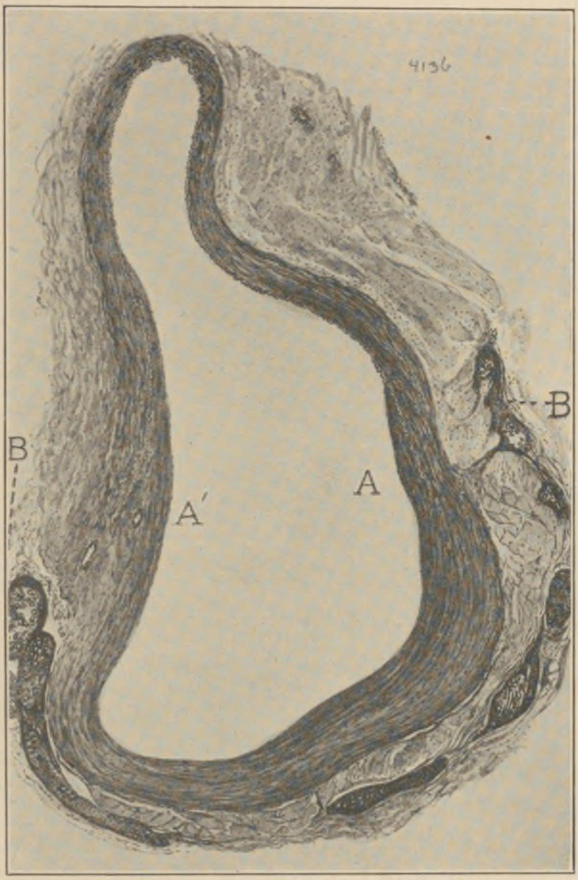

FIG. 54.—DRAWING OF A CROSS-SECTION AT THE SITE OF FASCIAL GRAFT FOR A DEFECT OF THE ABDOMINAL AORTA, NINE MONTHS AFTER OPERATION.

The upper half of the circumference is the arterial wall, contracted upon removal of the specimen. The lower half is the altered fascial graft. The termination of the arterial wall is indicated by the ending of the elastica opposite *A*, *A′*. The silk sutures, *B*, *B*, also indicate the place of fusion between graft and artery.

these cases, removed from six to nine months after operation, the tissue occupying the defect had the macroscopic appearance of fascia. There was no suggestion of aneurysmal dilatation in any instance, the transplant offering a firm and resisting support. The lumina of the vessels were entirely free in every case but one, in which a femoral artery was patched. Thrombosis and canalization occurred in this experiment. Microscopically, the transplants were found to have undergone fibrous tissue replacement to varying degrees, but the architecture of the original fascia lata persisted. The fusion between graft and arterial wall was complete, the termination of the elastica of the vessel being the only guide to the site of transition when the ordinary double staining methods were used. Flat cells continuous with the lining endothelium of the arteries covered the free surface of the grafts.

The technic of operation is simple, the only additions to the usual armamentarium being sterile vaseline and fine silk for suturing. Ether, by intratracheal insufflation, may be used for the operation on the

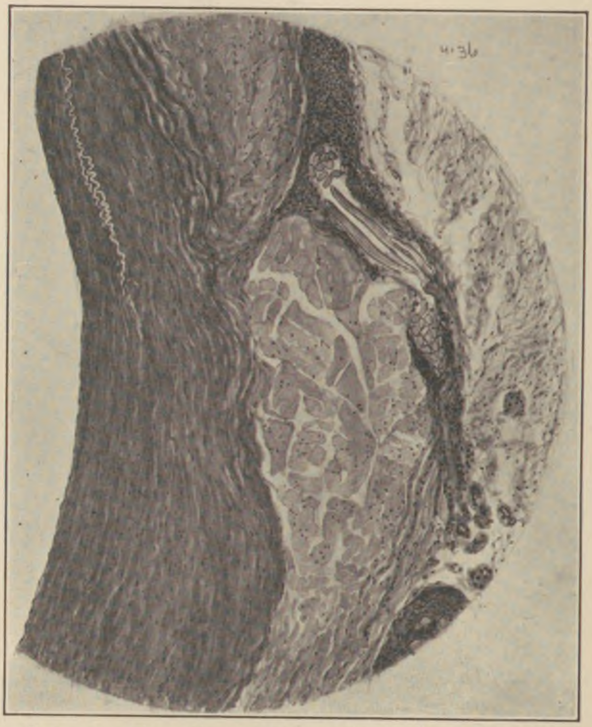

Fig. 55.—High Power Drawing at *A* in Fig. 54.

This shows the details of the fusion between arterial wall and fascial graft. The endothelial cells of the aorta have overgrown the free surface of the transplant. The termination of the elastica is the distinguishing mark of the transition from aorta to transplant.

thoracic aorta; by the rebreathing method for the other experiments. With the artery exposed and the portion from which the section is to be taken isolated, hemostasis is established by the application of rubber-protected clamps on both sides of the area to be resected and the ligation or temporary clamping of branches of the artery in the zone of operation. The desired section of the wall of the artery is then excised and the defect measured. Blood in the interior of the vessel is washed away and a gauze sponge, freely spread with vaseline, is placed over the exposed lumen. The fascia lata is then laid bare, a section of the desired shape and of slightly larger size is measured off, removed, dipped in vaseline, and immediately placed over the arterial defect with its smoother surface facing the lumen. The transplant is fixed in place by four sutures, then a continuous suture, approximating edge of fascia to cut edge of artery, is made between them. Compressing the patch lightly with a piece of vaselined gauze, the distal and then the proximal clamp on the artery are removed. If there is oozing from gaps between individual stitches, reinforcing ones are passed from the margin of the transplant to the adjoining arterial wall at those places.

Vascular suture and other methods of repair of arterial wounds were not extensively employed in the World War. The existence of infection in many of the wounded made ligation imperative even at the hazard of loss of a limb. Wounds of the popliteal artery were common, and ligation was the procedure that was ordinarily pursued. Although ligation of the accompanying popliteal vein was found to enhance the chances for a return of the circulation, the treatment of wounds of the popliteal artery by ligature resulted in gangrene in a considerable proportion of the cases. When gangrene and loss of the limb did not supervene, pain, claudication and the other manifestations of an impoverished circulation persisted in many of the patients. The indication for attempting repair of the injured vessel, whenever possible, therefore clearly existed, although such procedures were not, of course, feasible in the presence of a grossly infected or contaminated wound. Simple suture sufficed in small lesions of the popliteal artery, particularly when the injury was of recent origin. Complicated operations, such as resection and end-to-end suture and even blood-vessel implantations, were advocated for the more extensive vascular lesions. How often these were carried out and what results were obtained is not known, but it is reasonable to assume that failure was the rule except in the hands of surgeons specially trained in such work. I had the opportunity of operating upon two patients, two and four weeks, respectively, after wounds of the popliteal artery had been sustained. Large false aneurysms were present in both instances. The following report of the cases will indicate that suture of the defect in the arteries would have been either impossible or unwise, that replacement of the defects was required, and that the use of fascial grafts was followed by restitution of the circulation and, as a result, by the retention of useful limbs.

The first patient was seen ten days after having been wounded in the lower thigh by a small fragment of shrapnel. There was a typical popliteal aneurysm of large size, with the wound entrance almost healed. The foot was blanched and cool. No dorsalis pedis or posterior tibial pulse was felt in either foot. During six days' observation no change was observed in the size of the aneurysm. Operation consisted of incision over the sac and exposure of the artery above and below for the placement of temporary clamps. The thick-walled sac was then excised, blood-clots evacuated, and the lesion in the artery exposed. When trimmed, it consisted of a smooth defect occupying approximately half the circumference, the longitudinal diameter being somewhat greater.

The vessel was firmly bound down in this region, and its isolation was not deemed desirable because the branches for collateral circulation were given off in the immediate neighborhood, and their intact state was considered important should the operative procedure fail. Suture of the defect was impossible; resection would probably have resulted in too long a gap to be closed by end-to-end suture. It was, therefore, determined to attempt a fascial transplant. The technic was as follows: the fascia lata was exposed a short distance above the knee-joint and an elliptical section 2.5 by 2 cm., approximately the shape and size of the arterial defect, was removed. The sutures were vaselined and vaseline was freely applied to the surface of the transplant. The graft was fixed in place by four fine silk sutures. A continuous suture of fine silk was made between these points of fixation, approximating arterial edge to fascial edge. The approximation over the lateral aspects of the artery was somewhat difficult because the vessel wall was firmly fixed to the underlying tissues. Upon partial release of the clamps, there was bleeding at several points along the upper margin of the suture line and reinforcing stitches were here applied. The vessel was permitted to distend slowly by first removing the distal and then the proximal clamp. There was no bleeding. Slight bulging of the transplant was noted. The expansile pulsation of the vessel was good in the operative field as well as above and below it. No oozing occurred during some five minutes' observation and the wound was closed in layers. After operation, the foot remained warm and free from any evidence of interference with the circulation. During the period of ten weeks' postoperative observation there was no trace of recurrence of the aneurysm, and the circulation in the foot remained normal. The patient was discharged, free from symptoms, walking well, and with good motion at the knee-joint. Satisfactory progress was reported and the patient returned to active duty about six months after operation. A medical report nine months after operation stated that the lower extremity was in normal condition. A letter written three years after operation contains the information that the limb is perfectly normal.

The second patient was admitted to the hospital three days after having been wounded in the lower thigh. The point of entrance was over the inner aspect, about three inches above the condyle, the tiny fragment of shrapnel being lodged in the outer thigh, posterior to the femur. There was an extensive ecchymosis, induration in the popliteal space, and typical expansile pulsation over the arterial hematoma. Circulation in the leg and foot was good, both dorsalis pedis and posterior tibial pulses being present. It was thought that in the presence of the slightly infected wound of entrance and with the possibility of a small arterial defect that might heal over, operation should be deferred. This proved to be an error; although the swelling receded somewhat, the circulation in the foot became poor and the anterior and posterior pulses disappeared. Operation was performed four weeks after the injury. The sac was exposed, the artery provisionally clamped above and below as in the previous case, and the sac laid open. The lesion was found to be an arteriovenous aneurysm, the popliteal vessels being closely bound together. The vein was first separated and its long oval defect was closed by a continuous suture. The artery was then isolated and the margin of the defect trimmed from the false sac. The defect involved more than half the circumference, the lips gaping widely. Despite the long section of the vessel that was isolated in this case, these lips could not be approximated by transverse suture even with flexion of the knee, without placing undue tension upon the suture line. Longitudinal suture would have resulted in almost complete stenosis of the lumen. Fascial transplantation was, therefore, decided upon. The technic being similar to that employed in the previous case, it need be only briefly mentioned. The transplant was somewhat larger and in this case Carrel needles and sutures were employed. A few reinforcing stitches were necessary, after which through pulsation was noted upon removal of the clamps. There was no appreciable oozing between the sutures.

The subsequent course was satisfactory. Good circulation returned to the foot, the dorsalis pedis pulse reappeared, but there was some question as to the return of the posterior tibial. Upon discharge from the hospital, eight weeks after operation, the circulation in the foot was satisfactory, the patient was up and about, walking well with some limitation of motion at the knee-joint. Later reports were received, stating that there was no recurrence of the aneurysm. Two years after operation, the limb was normal, except for somewhat limited motion at the knee-joint. The patient was able to do heavy work without inconvenience.

FASCIAL TRANSPLANTATION FOR DEFECTS OF HOLLOW ORGANS

The question of fascial grafting for defects of the hollow organs, such as bladder, trachea, and urethra, and that of the reinforcement of doubtful suture lines presents an entirely different aspect of the subject. The problem is one of bridging defects of organs lined by epithelium and changing in shape at frequent intervals. It also involves the question of possible infection. We have indicated the fact that fascial transplants may heal in place in infected fields but necrosis and discharge of the graft is too likely an event for any general application of the method in the presence of infection. Would necrosis and discharge of the graft occur similarly if fascia were employed to bridge defects of hollow viscera? Should this transpire, no clinical use could be made of fascial transplantation, whereas many applications of the method might be made if the transplant maintained closure of gaps in the various hollow viscera. I conducted an extensive experimental investigation in an effort to solve this question and have applied the results of that work in some clinical problems.

The few previous attempts to bridge defects of hollow viscera were initiated by Koenig and Hohmeier. The former, in a series of experiments carried out in 1911, reported that leakage did not occur after fascial reinforcement of weak suture lines in the incised esophagus, stomach, intestine, and bladder, whereas leakage ordinarily might have been expected. He also applied the method in several operations upon the human being, with results that were not invariably satisfactory. Nevertheless, on the basis of his experiences, he advocated the use of fascia for such purposes. Hohmeier, in his experiments, went one step further; he attempted to bridge complete defects of the bladder, esophagus, and trachea by fascial sheets. His work is the source of statements in the literature to the effect that fascia has been used successfully for the repair of such defects. The unsatisfactory outcome of most of Hohmeier's experiments, especially with transplants into vesical defects, will subsequently be indicated. Kostenko and Rubaschew, as well as Joffe, demonstrated in a large series of experiments that it is, in most instances, essential to preserve the continuity of the mucous membrane of the hollow viscera in transplanting fascia over them. The only grounds for the rather generally held impression that the various hollow viscera have been successfully "patched by fascia" experimentally are the reports of very small tracheal and esophageal defects that have been treated in this way. There was but a single instance of successful fascial transplantation into a defect of a hollow organ in the human being, a case of tracheal fistula described by Levit.

On the other hand, Koenig's clinical results in the reinforcement of suture lines in the bladder led to similar successful attempts by other surgeons. These will be noted very briefly. Schmid reports a vesicovaginal fistula unsuccessfully operated upon a number of times. Finally, he closed the opening in the bladder, sutured a piece of fascia 2 by 3 cm. over it, and approximated the freed flaps of cicatricial vaginal mucous membrane. Healing followed. In several instances Bumm succeeded in supporting large cystoceles by implanting fascial sheets under the mucous membrane between the pubic bones; his report, however, was made shortly after the operations were performed, and the final results are unknown. Henschen was the first to employ supporting strips of fascia in a case of rectal prolapse; the result was perfect despite some suppuration in the wound and partial exposure of the transplant. From these reports, favorable conclusions as to the practical use of fascial transplants about the hollow viscera would naturally be drawn. It should, therefore, be stated that sloughing and necrosis of the transplanted fascia occurred in all the reported cases other than those above mentioned—fascial rings about a sacral anus after resection of the rectum, fascia over end-to-end suture after resection of intestine, fascia over the sutured urethra, and one case in the four fascial transplants reported by Bumm.

An analysis of all reported experimental and clinical observations leads to the conclusion that the success of fascial transplants over suture lines or in small defects of the hollow viscera, or into a frankly infected field, can always be considered problematical and in the nature of a fortunate accident. It is, therefore, not surprising to find that writers consider fascial transplantation neither desirable nor indicated under such circumstances. The results of my work were entirely different from those previously described and showed that a complete revision of the subject should be made. Despite my experimental and clinical studies, however, the practical aspect of fascial transplantation into defects of hollow viscera, as well as into ordinary infected fields, remains an open question. At the present time the following viewpoint is justifiable:

Necrosis of fascia transferred to the fields in question may result in a deep-seated phlegmon or a complicated fistula, and a serious complication—perhaps a fatal one—might follow the sloughing of, or perforation through, a transplant bridging a defect of one of the hollow viscera. *A priori,* therefore, no matter how satisfactory the experiments to be described, their application to the human being can be considered only when the usual surgical measures offer no promise of relief. This is the situation that exists in some of the more difficult problems that are encountered in surgery. It was in part as a suggestion for its solution that my studies in transplanting fascia into defects of hollow viscera were undertaken.

Vesical Defects.—The statements in the literature are erroneous in referring to appreciable vesical defects as having been replaced successfully by fascial transplants. They are based on studies by Hohmeier, Kostenko and Rubaschew. Upon analysis of Hohmeier's experimental work, it is found that the results were quite unsatisfactory. Four experiments were performed upon fascial implantation into bladder defects. In one, a "peritonitis from unknown cause" resulted in death a few days after operation. Perforation through the transplants occurred six and nine weeks after operation in two succeeding experiments. It was only in the fourth that "the fascia appeared firmly healed in place." In this instance death resulted from "distemper" three weeks after operation; the period of observation is, therefore, evidently not sufficiently long to suggest any definite conclusion, especially in view of the other experiences. Kostenko and Rubaschew found that fascial transplants occasionally prevented leakage from the bladder when implanted into very small defects. The periods of time after operation at which the observations were made are not given. Healing in these occasional instances depended upon shrinkage of the defect and approximation of the cut edges of the bladder wall. In general these experimenters agreed with Joffe, who demonstrated that fascia often prevented leakage when implanted over vesical defects after the mucous membrane had been sutured, but that necrosis of the transplant and perforation followed uniformly when the lips of mucous membrane were not approximated. On the other hand, the experiments of Koenig, Hohmeier and the others

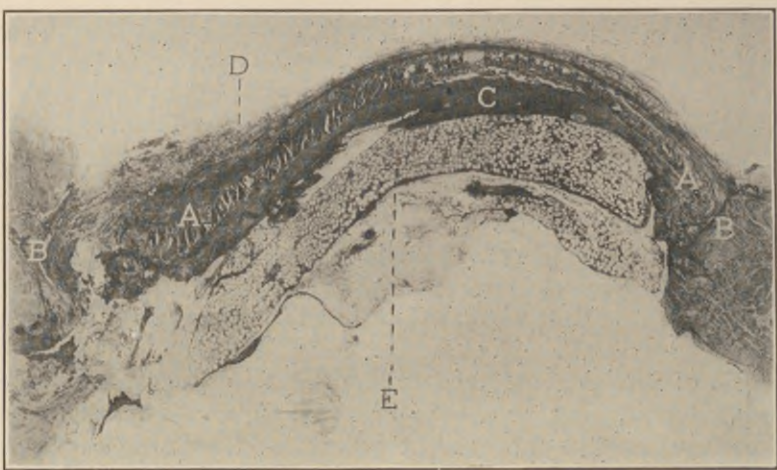

FIG. 56.—TWO DAYS AFTER FASCIAL TRANSPLANT INTO DEFECT OF BLADDER.

A, *A*, the two layers of fascia attached firmly to bladder wall at *B*, *B*. *C*, layer of fibrin. *D*, leukocytes on free surface. *E*, adherent omentum.

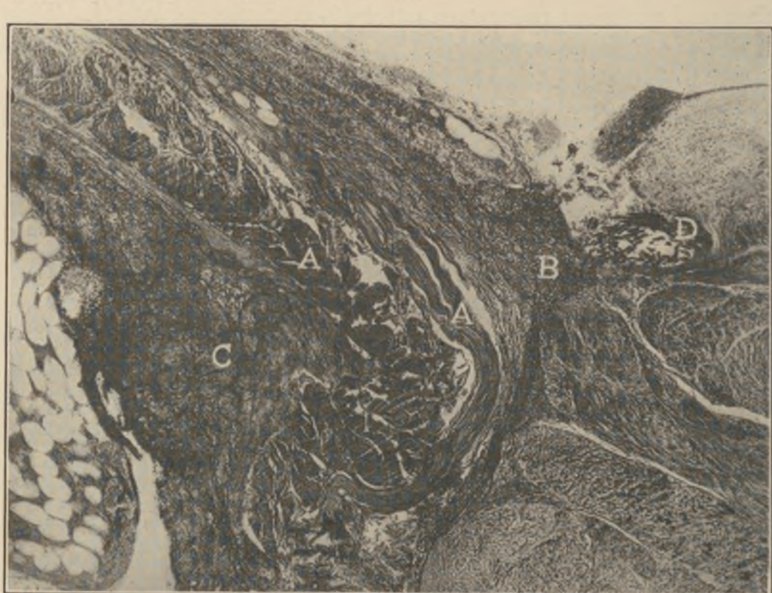

FIG. 57.—ENLARGEMENT AT *A*, *B*, IN FIG. 56, TO SHOW DETAILS OF REPAIR.

A, the two layers of fascia undergoing degeneration. *B*, thick layer of fibrin sealing the chink between transplant and bladder wall. *C*, layer of fibrin to which the omentum is adherent. D, silk suture.

above mentioned, demonstrated that fascia affords a strong barrier against leakage when transplanted over suture lines in the bladder.

The outcome of the experiments I performed was successful, even when as much as one-half of the bladder wall was replaced by fascia. Perforation followed in one instance only, in which about five-eighths of the bladder was replaced by fascia. Apart from the absence of contractility, the functional results were perfect; in fact, resistance to hydrostatic pressure was found to be greatest at and about the newly formed bladder wall. It is of interest to note that vesical calculi never developed when fascia was employed to replace the defect, but were present around fat transplants used for this purpose.

A remarkable feature of the experiments was the development of macroscopic plaques of bone at the site of transplantation. This metaplastic phenomenon began astonishingly soon after operation and

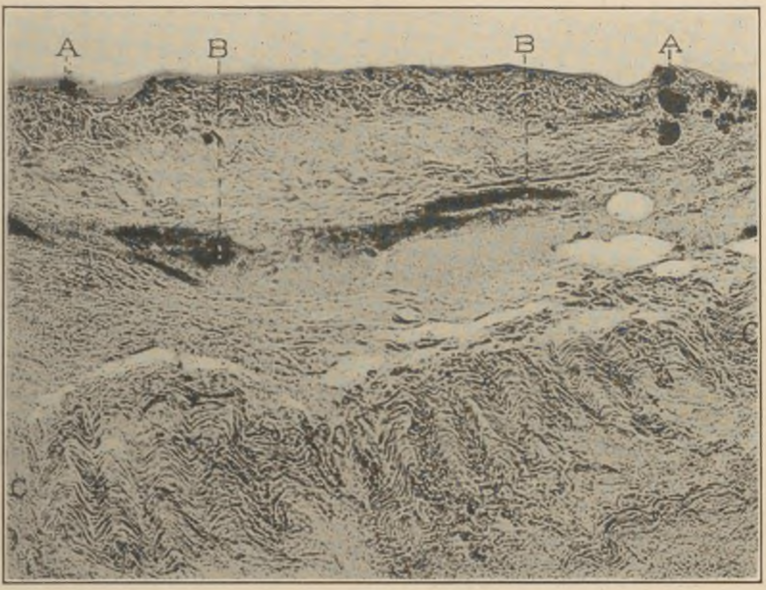

FIG. 58.—SIX DAYS AFTER FASCIAL TRANSPLANT INTO VESICAL DEFECT.

A, *A*, deposits of lime salts on the surface and *B*, *B*, in the depths. *C*, *C*, fascia undergoing hyaline degeneration.

reached its height in about two months. Relatively little significance might have been placed upon the formation of osseous tissue were it not for the fact that it developed invariably in all the experiments. Not only bone, but cartilage and bone marrow appeared, as well as an ensheathing tissue akin to periosteum. The development of bone did not in any way interfere with the functional result. On the contrary, this was probably enhanced by the increased strength of the newly formed bladder wall. The latter term is used advisedly, for the results did not depend upon healing by shrinkage of the defect, but upon the replacement of the defect by new tissue.

The only differences in technic from that employed by previous workers was in the implantation of transplants into and not over the vesical defects, the approximation being edge to edge. The importance of the general application of this method of fascial grafting has been emphasized and the argument for its adoption is based chiefly on the results I obtained in the experiments on defects of the bladder. There is no other adequate explanation for the opposite and unsatisfactory results arrived at by others.

Fat transplants were sutured into vesical defects in a few experiments I performed, in an attempt to determine if tissues other than fascia could be satisfactorily employed for the purpose. Although leakage did not occur, the functional results were unsatisfactory. Extrusion of the fatty tissue into the bladder took place, and the lips of the defect of the bladder drew together as the transplant was expelled.

FIG. 59.—SEVEN AND ONE-HALF WEEKS AFTER FASCIAL TRANSPLANT INTO A DEFECT OF THE BLADDER.

This shows the new-formed tissue occupying the defect. *A*, overgrown epithelium. *B* layer of bone with cartilage and marrow. *C*, periosteumlike layer of connective tissue with "osteoblasts" directly adjacent to the bone plaque.

The results were a diminution in bladder capacity and the formation of vesical calculi, particularly in one instance.

The process of repair after experimental fascial replacement of bladder defects is of considerable interest. In the first place, it is adequate. Granulation tissue disappears soon after operation, fusion between the tissues occupying the defect and those of the bladder wall is complete, epithelial overgrowth beginning at an early stage. The newly formed bladder wall is as strong or stronger than the remainder, contracts to an insignificant extent, if at all, and does not lead to the formation of vesical calculi. These characteristics were quite uniform throughout all the experiments. The formation of bone and cartilage is a remarkable development worthy of some discussion because of its bearing on the metaplasia occurring in or about tissue transplants.

It is out of place to enter here into the question of the tissues required for bone development. That previous bone or periosteum is not necessary for the formation of new osseous tissue is, of course, demonstrated by finding such tissue developed in situations far removed from the skeletal system. Our experiments showed clearly that the bone deposits occurred with concretions of lime as their beginnings, without any relation to blood-vessels, or to any of the tissues of the adjacent bladder wall. It might almost be said that the development of bone took place, in this situation, outside the body. This isolation is further emphasized by the fact that the deposit of bone was invariably limited to the site of the defect. The suggestion that fascia, genetically related to bone, was transformed into that issue, is manifesly invalidated by the fact that lime deposits and bone formation were found when fat was transplanted. Furthermore, it is to be noted that the fascia degenerates at an early stage, before the evolution of bone occurs.

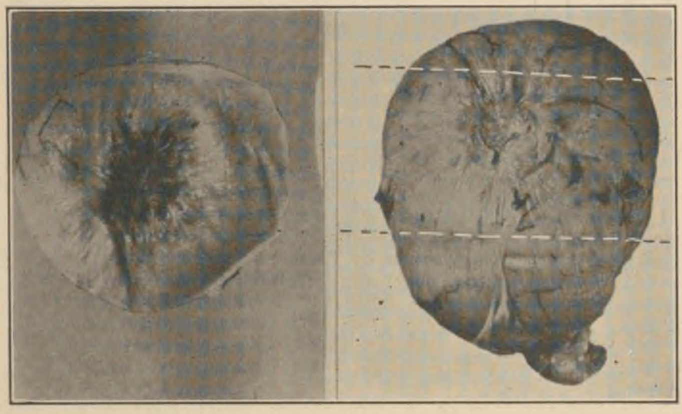

Fig. 60.—Two and One-half Months after Fascial Transplant into a Defect of the Bladder Wall.

The unopened and maximally distended bladder on the right, showing the resistance of the new-formed tissues (indicated by dotted lines) occupying the defect. On the left the opened bladder showing a bone plaque in the midst of the new-formed tissue of the defect.

The development of bone in these experiments can be explained only by the metaplasia of any connective tissue occupying the defect. That this was a development that may, in a sense, be termed "normal" for the existing conditions, is shown by its presence in every experiment. The reasons for, and the way in which, bone is laid down appear to me to be as follows: The tissue occupying the defect is being constantly subjected to great tension. The defect being too large to permit of obliteration, reinforcement of the tissues filling the gap is the result. A favorable opportunity to obtain reinforcement exists potentially in the presence of calcium salts in solution in the urine. These are laid down on the surface and are taken up in the depths of the transplant by imbibition. The lime deposits stimulate the surrounding connective tissue chemically or physically (or chemicophysically) to build up the most resistant barrier. Bone deposits are the result, with lime salts as their actual nuclei or their centers of stimulation. It is in this way that the microscopic findings in the experiments are best understood.

Furthermore, one can realize why the astonishingly early development of bone was not a degenerative phenomenon.

Ureteral Defects.—The experimental work of Kostenko and Rubaschew indicates that fascial transplantation over suture lines in the ureter is not a reliable procedure, for leakage of urine followed in several instances. In one experiment, however, at which an end-to-end anastomosis of the divided ureter was made and surrounded by a cuff

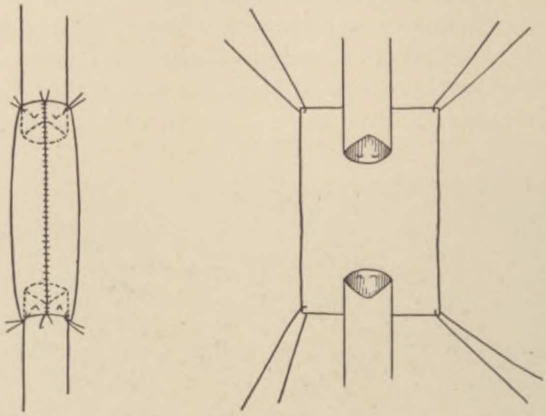

Fig. 61.—Diagram to Show the Method of Constructing a Fascial Tube between the Ends of a Resected Ureter.

of fascia, it was found that the suture lines in the ureter had separated and that the fascia was the only barrier successfully to prevent the escape of urine. Clinically, however, a case was reported by these authors in which fascia placed over the sutured ureter, after removal of a calculus, did not prevent leakage.

The clinical problem of replacement of ureteral defects has not been solved satisfactorily. Nephrectomy must be performed when end-to-

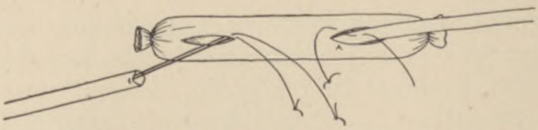

Fig. 62.—Diagram Illustrating the Method of Fixing the Ends of a Resected Ureter into a Previously Constructed Tube of Fascia.

On the right, the ureter is being drawn through a slit in the tube. On the left, the wall of the ureter is being fixed to the tube at the slit. The slits in the fascial tube are drawn too large.

end suture is impossible and the upper end of the divided ureter cannot be implanted into the bladder. It is surprising to find that so few experimental efforts have been made to solve the problem. Owing to the resistant qualities of fascia, we believed that tubes made of this material might satisfactorily replace ureteral defects. Although there was not a single completely successful experiment to support the view that the procedure is practicable, the failures encountered depended on several factors that can be eliminated in parallel surgical procedures in the human being. The best experimental results were obtained when a tube of fascia was first constructed around a glass rod buried in the thigh, then transferred to the ureteral defect two weeks later.

Esophageal Defects.—Brief reference has already been made to the experiments performed by Koenig and Hohmeier in reinforcing suture lines of the esophagus. Kostenko and Rubaschew repeated the work in a considerable number of experiments. They found that the transplant could almost invariably be depended upon to prevent leakage from such suture lines. On the other hand, necrosis and perforation of the fascia followed all attempts to replace appreciable defects—2 by 2 cm. or more—of all the layers of the organ. There were occasional successes in their efforts to bridge very small esophageal fistulae by

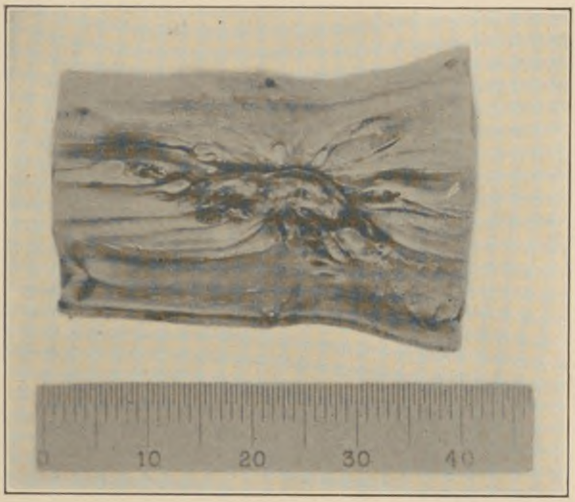

Fig. 63.—Appearance of the Interior of the Esophagus Two Weeks after a Fascial Transplant for an Esophageal Defect.

The irregular area is found to be more and more smoothed out in the later stages after operation.

fascial transplants, but these were found to depend upon obliteration of the defect and not upon upbuilding of new tissue. These observations have no further practical significance than to suggest that suture lines in the esophagus may be reinforced satisfactorily by fixing fascial strips over them.

Despite the results noted above, we believed that large defects might be successfully replaced by fascial transplants with the modification in technic that we employed. It was essential, however, that little or no esophageal stenosis should follow; otherwise the procedure would be no better, in fact, less desirable than ordinary suture or plastic methods. Only a few experiments were necessary to demonstrate that large defects, involving as much as the entire anterior aspect of the esophagus, could be satisfactorily bridged in this way. Granulation tissue appeared on the surface of the transplant soon after operation. In the later stages the defect was found solidly filled by partly contracted connective tissue (representing the altered fascia) and entirely covered by epithelial overgrowth. The results were good anatomically and functionally. Slight stenosis was observed in an experiment concluded two weeks after operation; this was less evident in an experiment three weeks after operation, and was almost imperceptible after four weeks. In view of the infected state of the animal esophagus, the unavoidable movements of the head and neck after operation, and the necessary administration of nourishment by mouth soon after operation, it seems fairly safe to believe that the expectation of success after fascial transplants into esophageal defects in the human subject can be even greater than in the experiment. The present-day

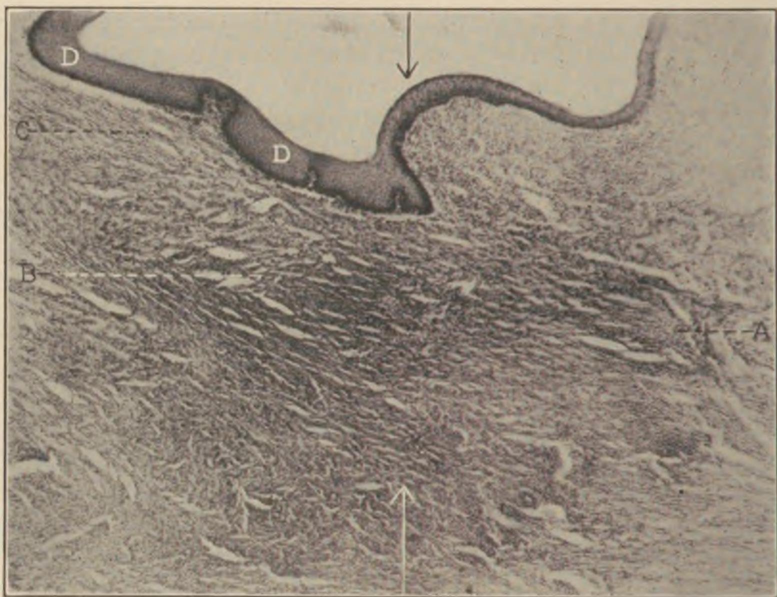

FIG. 64.—SIXTEEN DAYS AFTER FASCIAL TRANSPLANT INTO DEFECT OF ESOPHAGUS.

Arrows indicate line of transition from esophageal tissues (to the right) to those of the defect (to the left). *A*, muscle layer of esophagus. *B*, degenerating fascia. *C*, organized granulation tissue on the surface of the transplant. *D*, *D*, regenerated epithelium raised in folds.

treatment of small esophageal fistulae is simple and efficient. The attempt to close larger defects (as after excision of a diverticulum, sloughing from impacted foreign body, etc.) involves complicated plastic procedures, the usual results of which cannot be termed satisfactory. It remains for the future to determine if fascial transplantation, readily accomplished technically, can offer better results.

Gastric Defects.—Attention has been called to the attempts by various experimenters to support suture lines of the stomach by transplanting strips of fascia over them. The experiments did not demonstrate that this procedure offers definite assurance of additional reinforcement. Attempts to replace all the layers of the stomach failed invariably, even when the defects were very small.

These attempts were repeated by me, in a number of experiments, with the described modification in technic. Failure followed in every instance. Perforation through the necrotic transplant always occurred, no matter what technic was employed. Apparently the transplanted fascia was attacked by the gastric juices and its disintegration promptly followed. This view was supported by the fact that the perforation was

FIG. 65.—EIGHT WEEKS AFTER FASCIAL TRANSPLANT INTO DEFECT OF THE STOMACH. *A*, well-developed mucosa resting directly on bone plaque, *B*. *C*, artefact.

almost invariably near the center of the transplant, and not a separation of the suture lines.

Finding these efforts to replace gastric defects by fascia quite futile, it appeared of interest, in relation to experiences in the human being, to inquire if gastro-enterostomy would in any way influence the result. I found that gastro-enterostomy does play a decisive rôle, for the fascial transplant heals in place in the presence of an anastomosis. Exclusion of the pylorus was manifestly not a factor, for the results were quite satisfactory without it.

A remarkable feature was the formation of true bone in the tissues at the site of the defect. This is merely mentioned here, for the question of bone formation was considered in the section devoted to fascial transplantation into bladder defects. The conditions were analogous except that, in the bladder experiments, the necessary calcium salts were, of course, much more readily accessible.

Defects of the Small and Large Intestine.—Reinforcement of suture lines in the intestinal wall has been attempted, both clinically and experimentally, with varying results that have already been mentioned. No effort had been made to replace actual defects in either the large or small intestine at the time our work was done. Our experimental studies showed that transplants into defects in the upper part of the small intestine generally failed. Small transplants in the lower part of the small intestine were often successful, but the replacement of larger defects not infrequently failed. On the contrary, fascial implantation into large defects in the large intestine succeeded in two out of three experiments. In short, there have been failures after transplants into defects of small and large intestine of about the same size as those that have been successfully bridged. These results indicate that fascial transplantation into intestinal defects is not a reliable procedure. They are not comparable with those obtained in the esophageal and vesical defects or in the tracheal defects to be described.

Tracheal Defects.—The first experimental work in this field was performed by Hohmeier. He found that fascia could be successfully transplanted over very small tracheal defects (one-half to three-quarters of a square centimeter), and that flat epithelium grew in part over the granulation tissue occupying the surface of the defect. Davis, in replacing similarly small (8 by 8 mm.) defects, found that complete epithelial overgrowth occurred. Larger areas (less than 2 by 2 cm.) were replaced by fascia in a series of experiments reported by Kostenko and Rubaschew; here, however, overgrowth of tracheal epithelium was not seen.

Fascial replacement of minute tracheal defects has little practical importance, since ordinary surgical methods can accomplish a cure. If the work of Kostenko and Rubaschew were to be accepted, the replacement of somewhat larger defects by fascia is undesirable because the exposed granulating transplant would be apt to lead to complications. Clinically, the cure of large defects of the trachea is as yet an incompletely solved problem. Complicated plastic operations have been devised in the effort radically to close these fistulae. Flaps from the sternum or clavicle have been turned upward to supply the necessary rigid layer of tissue in the gap. For tracheal fistulae at a high level, flaps from the thyroid or cricoid cartilages have been used. Resection followed by end-to-end suture of the trachea has been practiced. There have been failures after all these advocated procedures.

If experimental transplantation of fascia into large tracheal defects proved completely successful despite the difficulties that exist in the care of animals after such operations, it might be said that the application of this procedure to the human being offered the most logical method of treatment. In my experiments it was found that very large tracheal defects could be replaced satisfactorily by transplanting fascia into the defect. Only slight stenosis followed. The ciliated tracheal epithelium grew completely over the transplant after operation. Both anatomically and functionally the results were well-nigh ideal. In our first experiment, the transplant was sutured over the relatively small defect after the method advocated by Hohmeier and others, and leakage and pretracheal suppuration followed. In all succeeding experiments, larger defects were invariably successfully replaced by fascial implan-

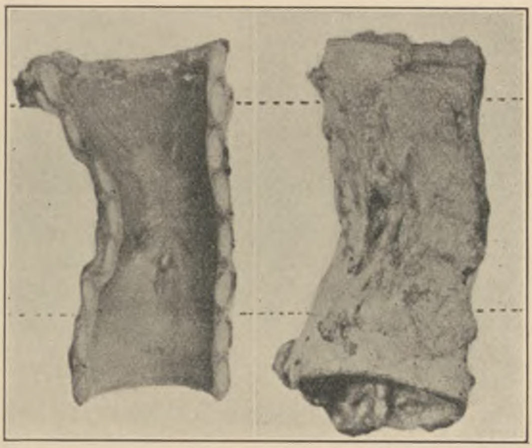

Fig. 66.—External and Internal Views, Eight Weeks after Fascial Transplant into Large Tracheal Defect Involving Three Rings.

Site of defect between the dotted lines. Hardened specimen, exaggerating distortion.

tation into them, without any technical difficulty or postoperative complications.

Reference has been made to the one instance in the human being of successful fascial transplantation into a hollow visceral defect—Levit's case of fascial transplantation into a defect of the trachea. He was led to employ this procedure by Hohmeier's experimental studies and because of the disadvantages of the usual operations that had been employed for the cure of tracheal fistula. An outline of his case follows:

An anterior median tracheal fistula, a short distance from the cricoid cartilage, followed attempted suicide. Three separate efforts to close the fistula by plastic operations failed. Levit operated under local anesthesia. He removed a section of fascia lata the size of a five cent piece (Silbergulden) and placed it in a saline solution. The margin of the tracheal defect was freshened, and the fascia placed over it with its superficial surface facing the lumen. The size of the defect is not stated; the transplant overlapped it by several millimeters. The margin of the fascia was attached to the adjacent surface of the trachea by interrupted sutures. Some leakage of air and flapping of the transplant were noted, and additional catgut sutures were, therefore, placed. The skin was undermined and sutured over the fascia.

The wound healed by primary union. Cosmetically and functionally the result was excellent. By laryngoscopic examination the site of operation was represented by a flat white circular scar about 10 to 12 mm. in diameter; the lumen of the trachea was slightly narrowed at this level. The patient was well eight months after operation.

In our case (a tracheal fistula following tracheotomy for diphtheria), the technic of operation was somewhat different, the fascia being transplanted into and not over the defect.

The patient desired relief for the cosmetic deformity and difficulty in phonation. A tracheotomy had been performed ten years before, but the wound had never closed. An attempt to heal it by

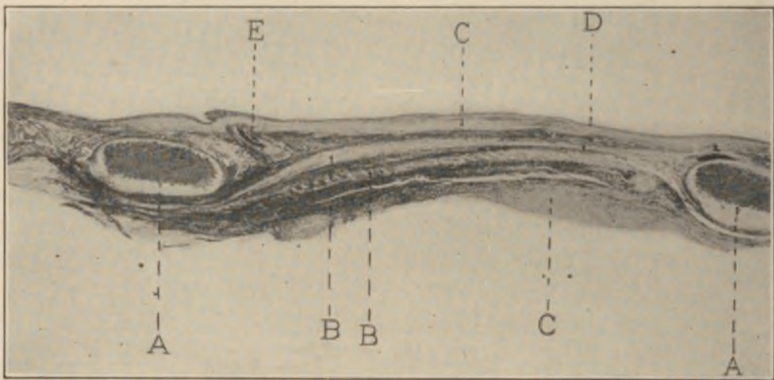

Fig. 67.—Longitudinal Section through Trachea at Site of Fascial Transplant, Three Months after Operation.

A, *A*, cross-section of cartilage rings at both sides of defect. *B*, *B*, the two layers of fascia lata. *C*, *C*, layers of connective tissue covering fascia. *D*, layer of ciliated epithelium grown over the defect. *E*, silk suture.

cauterization failed. The patient coughed almost constantly, but did not complain as much of this as of the other manifestations.

The voice was husky, but was made clearer by placing a finger over the fistula. The latter was situated in the midline in the lower part of the neck, at the level of the thyroid isthmus. The visible gap in the cicatricial skin was small, measuring about 1 cm. There was no evidence of stenosis above the fistula.

At the operation, under local anesthesia, the cicatricial tissue and skin about the tracheal opening were excised. The defect in the trachea was freshened and was found to be almost circular, measuring about 2 by 1¾ cm. A section of fascia lata, slightly larger than the defect and of the same shape, was removed from the lower thigh and at once transferred into the hiatus. The muscle surface of the transplant faced the lumen of the trachea. The fascia was fixed to the tracheal wall by four fine catgut sutures, and a continuous suture was made between them. In view of the possibility of leakage of air with the development of subcutaneous emphysema, a small rubber-tissue drain was placed down to the transplant. The remainder of the wound was sutured after the skin had been mobilized.

The transplanted fascia healed in place without reaction and there was no evidence of tracheal stenosis. Coughing was subdued but almost constant for the first few days after operation, but disappeared thereafter and did not return. The wound healed by primary union. In the first weeks, the field of operation bulged slightly with straining efforts, but the wound remained flat thereafter. Direct tracheoscopy could not be performed; by laryngoscopic examination the site of operation was indistinctly seen as a pale, flat, apparently smooth patch.

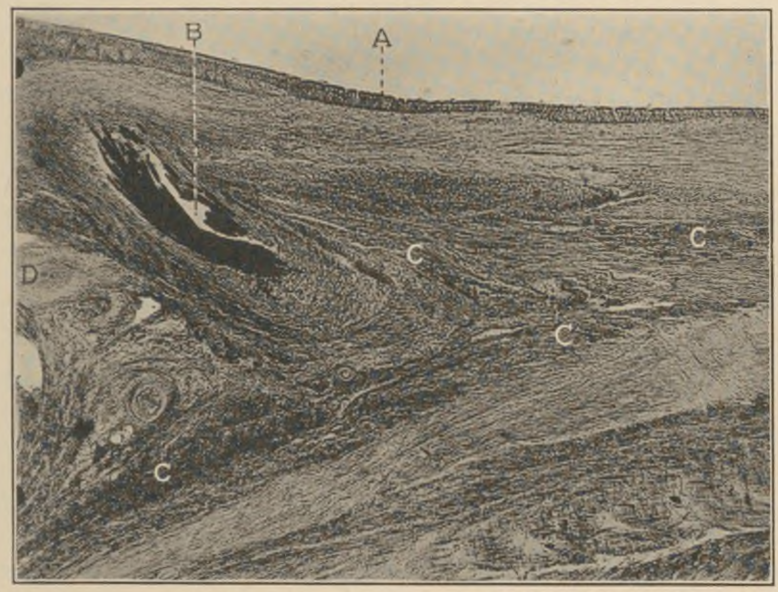

FIG. 68.—ENLARGEMENT AT *E* IN FIG. 67.

A, continuous layer of ciliated epithelium, the cilia indistinctly shown. *B*, silk suture. Intimate fusion of degenerating fascia, *C*, *C*, *C*, with connective tissue. *D*, cartilage ring.

The patient has remained well. Phonation is good. There is no cough. The field of operation is flat, smooth and firm; no infiltration is to be felt.

The fact that the operation of fascial transplantation has been successful in two cases of tracheal fistula does not of course establish it as the one operation for the condition. It is unquestionably a much simpler, far less formidable procedure than the operations usually employed.

Urethral Defects.—Large fistulae of the urethra can be cured by operations consisting in mobilization of the urethra, with or without the addition of plastic flaps taken from the corpora cavernosa, etc. However, failures have followed such procedures and incomplete results have also been reported.

Leakage after suture of the urethra is a complication not infrequently observed, and the means taken to prevent it have not proved entirely adequate. The experimental reports of satisfactory reinforcement of suture lines in hollow viscera by fascial grafts, and the successful clinical experiences in fascial reinforcement of sutures of the bladder, led to attempts to fix fascial strips over suture lines in the urethra. The results were not encouraging. Of four cases described in the literature, only one was an unqualified success. This was a patient reported by Bachrach, in whom a urethral fistula persisted after incision of a postgonorrheal abscess. The margin of the defect was freshened, the mucous membrane sutured, and a strip of fascia lata fixed over the suture line. The wound healed by primary union and the patient remained well and free from stricture at the site of operation. In two of the three remaining cases (Kleinschmidt, von Hacker), total failure followed fascial transplantation over urethral suture lines, the fascia becoming necrotic and ultimately expelled, and the fistula recurring in both instances. The fourth case (Hohmeier) may be termed an incomplete success. There was no leakage for eight days after an operation consisting of mobilization of a urethral fistula and suture of fascia over the defect. Then upon attempted replacement of the permanent catheter that had been used, the tip of the instrument passed through the field of operation. Leakage of urine and discharge of small fragments of necrotic fascia followed. However, most of the transplant remained in place and the fistula ultimately closed.

Considering the unsatisfactory results after transplanting fascia over urethral suture lines, is it justifiable to advocate the replacement of a urethral defect by a fascial transplant? With experimental experiences, as well as failures after suture and plastic methods in mind, we believed it fair to attempt this in the case to be described, the first in which the method was employed.

The patient, a boy nine years old, had had leakage of urine from the under surface of the penis since birth. At the age of three an operative attempt at cure of the condition failed. There was complete nocturnal incontinence of urine. The patient had occasional good control during the day, but he wet himself frequently. When voiding voluntarily, much of the urine (approximately one-half) usually escaped from the floor of the penis, the remainder from the tip. Sometimes most or all of the urine was discharged from the fistula. There was almost always pain on urination.

On the under surface of the penis, a short distance behind the glans, there was a slightly depressed orifice about 2 mm. in diameter, surrounded by cicatricial skin. The adjacent subcutaneous tissues were infiltrated. A probe entered the urethra without difficulty. The urinary meatus admitted a good-sized sound that could be passed into the fistula at will, but had to follow the dorsal surface to pass into the urethra beyond.

At operation, an elliptical section of the cicatricial skin about 2 by

1½ cm. was excised, together with the short fistulous tract. The defect in the floor of the urethra was then found to involve practically all of its ventral aspect, measuring approximately 1½ cm. in width and 2 cm. in length. The edges were freshened. A section of fascia lata slightly larger in size and of the corresponding shape was removed from the lower part of the thigh and sutured into the defect. Its muscle surface was turned toward the lumen. Interrupted sutures of very fine catgut were passed from the transplant through all the layers of the urethra at the margin of the defect. As a result, the fascia was firmly fixed in place, its margin slightly overlapping the margin of the urethral defect. The skin was mobilized and approximated over the transplant with slight tension.

The patient voided normally for the first few days after operation. The dressing was then found to be damp and the wound was inspected. The lowest skin suture had separated, and a small area of the transplant was here exposed. Several drops of urine escaped with urination. This persisted for several days. By the time the skin sutures were removed, eight days after operation, the wound was found firmly healed except at the lower angle, where a very small patch of fascia was exposed beneath the slightly separated skin. At that time only one or two drops escaped on urination. Two days later there was no escape of urine, although the skin had not healed over. There was no leakage at any subsequent period. The wound healed slowly at the lower angle, the transplant not being completely covered in until two weeks after operation.

At an examination about one month after operation, urination was normal, the wound was found firmly healed, a slight infiltration being palpable in the depths. This became more pronounced subsequently, so that at the end of six months a definite plaque was palpable in the scar. In view of the experimental experiences in fascial transplantation into vesical defects, the possibility of bone formation in the transplant was considered. Roentgen-ray examination was negative, however. The plaque gradually diminished in size and firmness and finally became imperceptible. It is significant that a satisfactory result was obtained, even though a permanent catheter or suprapubic cystotomy was not employed.

There was never any evidence of stenosis as determined by sounds upon a number of occasions. When the urethra was distended with fluid, the urethral canal was found normally distended at the site of operation. Nocturnal incontinence ceased promptly after operation and did not return.

The result obtained in this case recently led Brenner to employ a fascial tube for the replacement of a total urethral defect with a satisfactory result. Several operations had been unsuccessful in curing the fistula at the base of the penis, the result of an injury. At operation he sutured in place a tube of fascia, making an end-to-end suture between it and the separated ends of the completely severed urethra.

Although a stenosis has resulted, it is possible to dilate this by sounds and the functional result is satisfactory. This is the first case, to our knowledge, in which a fascial tube has been used to replace a urethral defect.

The Clinical Value of Fascial Transplantation.—I have placed greater emphasis upon the details of the different clinical applications of fascial grafting, proposed and practiced, than on those of any other tissue used for transplantation. This has been done because many personal experiences have convinced me of the value of transplanted fascia in numerous conditions otherwise not readily amenable to surgical treatment. A recapitulation is unnecessary. In some fields it is of proved value, in other fields final conclusions cannot be drawn. The method serves no useful purpose in some situations for which it has been advocated and this fact has also been indicated; there remain some fields for its application in which clinical trial is awaited. Fascial transplantation offers a wider scope in reparative surgery and a more varied sphere of usefulness than any other form of tissue transplantation.

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CHAPTER V

THE TRANSPLANTATION OF MUSCLE AND OF NERVES

MUSCLE

The free transplantation of striated muscle is not a method of established usefulness in surgery. Except for its hemostatic properties, muscle as a transplant has proved of little clinical value. The first work to appear on the subject was a publication of Zielonko, in 1874. He transplanted muscle tissue into the lymph sac of a frog and noted rapid necrosis of the graft without any evidence of regeneration. Gluck, some years later, claimed to have transplanted successfully small pieces of muscle into muscle defects. At the end of forty days, the transplant was described as healed in place and able to contract when stimulated directly or indirectly through the nerve. In a few experiments, inflammation and suppuration occurred with conversion of the transplant into a thick fibrous mass. On the basis of these results Gluck maintained that the autotransplantation, homotransplantation, or heterotransplantation of muscle could be successfully accomplished if proper aseptic precautions were observed. Gluck's work led Helferich to attempt the procedure clinically. He implanted a section of muscle obtained from a dog into a defect of the biceps consequent upon the removal of a tumor. After three months, electrical stimulation "showed a return of normal function to the muscle."

Successes with homoplastic muscle grafts in dogs were then reported by Salvias, who could find no differences between the transplant and the surrounding muscle, either macroscopically or microscopically, three months after transplantation.

The supposedly successful results with all types of transplantation, not only in heterotransplantation and homotransplantation but in autotransplantation as well, were not accepted by all investigators. Thus Magnus repeated the experiments and, after careful histologic studies, refuted Gluck's assumptions. His specimens showed degeneration, absorption, and fibrous replacement of the transplanted muscle. The defects became filled by newly formed muscle fibers, but this was apparently a regeneration from the musculature of the host. At a later date, Volkmann definitely established the fact that muscle, completely severed from its attachments, dies even if returned to the site from which it was taken. His observation that free muscle transplants necrose and are replaced by fibrous tissue has been substantiated by the work of later investigators.

The study of muscle transplantation was later approached from the aspect of nerve stimulation and functional stress. This followed logically after Roux enunciated his theory that the survival of any transplant was dependent on the functional stimulation it received. Jores and Schmid were the first to attempt an application of this principle to muscle transplantation. In their experiments, free muscle grafts were stimulated six to eight hours after transplantation. A weak faradic current was used for the purpose and faradization was repeated six or seven times daily. Jores and Schmid reported that the electrically stimulated muscle transplant healed in place. Although degeneration was seen, microscopically, regeneration of the muscle fibers occurred. At the end of two months no differences could be noted macroscopically between the graft and the normal tissue of the host. In grafts that did not receive electrical stimulation, no regeneration of the muscle was noted. Later careful experimental and clinical studies, however, have not corroborated the results obtained by Jores and Schmid.

Since muscle function disappears and atrophic changes occur in muscle when its nerve is severed, it was thought by Hildebrand that the sole important factor in muscle transplantation was the preservation of the nerve supply. He, therefore, undertook some experiments in which muscle with the nerve attached was transplanted, but found that the preservation of the nerve supply alone was not sufficient to maintain viability. Since it has been proved that an intact nerve supply cannot sustain the viability of a muscle transplant, the chances for success are even smaller in nerve suture or nerve implantation into muscle, as practiced by Goebell and Eden. The various procedures advocated for neurotization of muscle transplants, such as the implantation of a nerve stump (Haberland) or contact with healthy muscle (Erlacher), are, therefore, not based on logical grounds. The few instances in which free muscle transplants have actually become neurotized (Saltykow, Borst) have shown a very limited and merely transient regeneration of muscle fibers. Attempts to maintain the blood as well as the nerve supply of the graft have also resulted in failure.

From an examination of the work that has been done, it is evident that, regardless of the procedure employed, free muscle transplants invariably die, are replaced by fibrous tissue, and fail to resume their function. The peculiar feature about muscle transplantation is that in no instance is muscle tissue the end result of the operation. There can, therefore, be no clinical application of muscle grafting when muscle function alone is the desired object.

Histologic Changes.—Shortly after transplantation, evidences of degeneration are seen in the muscle. The muscle fibers become broadened and swollen. The cross striations disappear in large part at an early period. Degenerative changes occur in the nuclei, leading to their ultimate disappearance. A marked round-cell infiltration of the transplant occurs, especially pronounced at the periphery. Surrounding the transplant is a richly cellular granulation tissue crowding between the muscle fibers of the graft. The degenerative phenomena are much more marked in the central portion of the graft, only remains of muscular fibers being recognizable in the necrotic mass. Remnants of muscle fibers, converted into homogeneous areas, are scattered here and there. The line of demarcation between graft and healthy muscle is not sharply defined. A few of the muscle fibers remain well preserved for some time at the edges of the graft and even show signs of nuclear proliferation. A vacuolization of the greater part of the preserved muscle follows. Finally, the transplant is completely converted into a thick fibrous connective tissue containing a few muscular elements at the periphery. The latter are probably remnants of the normal adjacent muscle included in the reparative process. It is evident, therefore, that

FIG. 69.—SEMIDIAGRAMMATIC DRAWING TO SHOW THE CHANGES IN AN AUTOGRAFT OF MUSCLE AFTER ONE WEEK.

The muscular bed in which the graft was placed is seen at the extreme left. Note the degenerative changes in the graft, with partial or already complete destruction.

a free muscle transplant rapidly degenerates and is replaced by fibrous tissue without any evidence of subsequent regenerative phenomena.

The Clinical Application.—The original purpose in muscle transplantation was the replacement of muscles that had become useless because of disease or injury. This object has not been attained. There is no indication for muscle grafting for small muscle defects, adequate repair occurring after suture. The transplantation of muscle is futile for the replacement of larger defects, degeneration and fibrosis of the graft being the end-result.

The most important clinical application of muscle grafts is for the purpose of hemostasis. Experimentally, Laewen was the first clearly to demonstrate the feasibility of using muscle for the control of oozing from parenchymatous organs. Detached fragments of muscle in the form of so-called "postage stamp" grafts have been extensively used in surgery, particularly in operations on the brain. Small sections of muscle are detached from the operative field, placed over the bleeding point, and held in position by gentle pressure. The gloved finger is most useful for this purpose, as the graft does not adhere when the pressure is removed. We have also used muscle grafts for the control of oozing areas after the removal of tumors of the spinal cord. The procedure is particularly useful here whenever a ligature might injure the cord substance. Whether or not muscle grafts are superior to fat or other tissue grafts for hemostatic purposes remains unproved. Some have maintained that all tissue transplants are about equally useful for the purpose. It is our belief that muscle grafts are preferable because of the fact that they undergo degeneration and absorption much more rapidly than other tissues that are used for hemostasis. The ultimate fibrosis following muscle grafts would, therefore, be much less massive and this is an important consideration in neural surgery. Muscle grafts have also had an extended use for hemostatic purposes in other surgical fields.

Free muscle grafts have been employed for the obliteration of tissue defects, especially in bone. Not only experimentally but also clinically, satisfactory results have been obtained. A muscle graft serves the purpose of filling bone cavities as well as any other tissue transplant but is usually applicable for small defects alone, because of limited availability. Reports have been made of the use of muscle grafts for the closure of wounds of the heart. In two successful cases described by Laewen, the transplant promptly adhered to the wound and adequately sealed the perforation. Direct suture of wounds of the heart, however, is a simpler, safer, and an equally rapid procedure. Muscle flaps have been used by Robson for the closure of pericardial defects, but fascial transplants would better serve the purpose (see Chapter IV).

Muscle grafts have been advocated to secure suture lines in the same manner as fat grafts. Navratil, for example, attempted to reinforce a suture line in the esophagus by means of flaps from adjacent muscle. Because of the fact that muscle does not adhere as readily to the suture line as other tissues, and because of its structure, it is not of as much value as fat or fascia for the reinforcement of suture lines.

In vascular surgery, free muscle flaps have been used both experimentally and clinically to aid in the process of repair. Muscle was thought to be of considerable value in protecting suture lines of blood-vessels because of its hemostatic action. However, if oozing is not adequately controlled after blood-vessel suture, little can be expected of a muscle graft. Implantation of muscle into appreciable vessel defects has been advocated, but it is a dangerous procedure, for, in addition to the difficulty of adequately closing the defect, there exists the probability of thrombosis or embolism occurring during the period of degeneration of the muscle tissue. We have shown that fascial grafts are efficacious for the replacement of blood-vessel defects (see Chapter IV), and such grafts lend themselves much more readily for the purpose if any graft is to be employed.

The Clinical Value.—For hemostatic purposes in surgery, particularly in the surgery of the brain and spinal cord, muscle grafts are of great service. They are also useful for the obliteration of small sterile bone cavities. Muscle grafts are of no value for the replacement of muscle defects because early degeneration and fibrosis regularly occur.

NERVES

The first well-known clinical effort to bridge a nerve defect by a transplanted nerve was made by Albert, in 1885. The procedure has been repeated since that time with many variations in technic. To judge by the literature on nerve transplantation, every conceivable result has been obtained, from absolute failure to early return of function. In tracing the development of the subject, one is impressed by the fact that the earlier reports in the literature presented the most brilliant results, successes being less and less frequently described as time went on. Even at the present time there is no unanimity of opinion as to the advantages inherent in grafting detached nerve segments into nerve defects, but it may be safely said that the widespread enthusiasm for the method has been largely dissipated as a result of studies made in recent years.

Information concerning the outcome of nerve grafting is peculiarly dependent upon experimental work, for in this way alone can the processes of degeneration and repair be carefully observed. The original impression, upon which the belief in the practicability of grafting nerves was based, was that the transplant remained viable. In the early experimental investigations the persistence of autografts and degeneration of homografts and heterografts was described by some observers, and viability of all types of grafts claimed by others. A third group believed that degeneration occurred with any form of nerve transplantation. It was not until recent years that accurate criteria of the life or death of nerve grafts were formulated. These need not be detailed here. Two interesting features, determining the viable or non-viable state of the transplant, may be mentioned: the reaction to specific stains, and the condition of the cells of the sheath of Schwann. Concerning the latter, proliferation of the cells is an index and, according to Ingebrigsten, the only index of the viability of the transplant.

With the accurate criteria of viability that have been established recently, investigators are more generally agreed on the results of autotransplantation, homotransplantation, and heterotransplantation of nerves. In histologic examination, autografts are found to undergo degeneration, but the Schwann cells survive and may proliferate for varying periods. Similar changes are seen in homografts; however, the cells of Schwann usually disappear after a short interval. Proliferation of the cells of the neurilemma and Wallerian degeneration are not seen in heterografts, complete necrosis occurring within a few weeks. With this evidence, Ingebrigsten argued that heterografts are unsuitable for the replacement of nerve defects. On the other hand, the presence of Wallerian degeneration in autografts and homografts, similar to that seen in the distal portion of a nerve after severance, means that channels for the downgrowth of the new axis cylinders exist and that conditions are, therefore, favorable for neurotization through the graft.

In the brief description we have given of the histologic changes occurring in the graft itself, the later alterations, depending on replacement phenomena, were not taken into account. Fibrosis occurs as with

Fig. 70.—Microphotograph of Cable Transplant after Twenty-six Days.

Cross-section through middle of transplant. Ranson pyridine silver stain. Note that the funiculi are filled with downgrowing neuraxes (Stookey).

other transplants, but the physical characteristics of the newly laid down tissue varies with the type of graft. In autografts it appears that the replacing tissue is more loosely woven and follows the pattern of the transplant more closely than in homografts, while dense fibrous tissue is the usual sequel after heterotransplantation. Better results may, therefore, be anticipated with living autografts and homografts. The use of such heterografts as calves' arteries, hardened in formalin or alcohol, must result in an excessive amount of resistant fibrous tissue, than which there exists no greater opposition to nerve regeneration proceeding from the proximal stump.

The use of heterografts of nerves "preserved" in alcohol for the replacement of nerve defects has been proposed by Nageotte and others.

Although he maintains that "revivification" of other grafts occurs after "preservation" in alcohol, Nageotte states that this does not apply to nerves. The rôle of the alcoholized nerve graft is supposed to be purely mechanical, and fibrosis with consequent obstruction to neurotization will not occur, according to Nageotte and other observers. At the same time the usual reactions seen about a foreign body are said to remain absent. It is impossible to submit these statements to any critical analysis, for they are at variance with all other observations and very scanty evidence is offered for their support. Nevertheless the method has been employed clinically in a number of cases and good results have been reported.

A thorough investigation of the results of the various types of nerve transplantation has been made by Huber. His studies, extending over a period of many years, comprise the most complete and accurate work done in this field. Huber showed that the same or similar results were

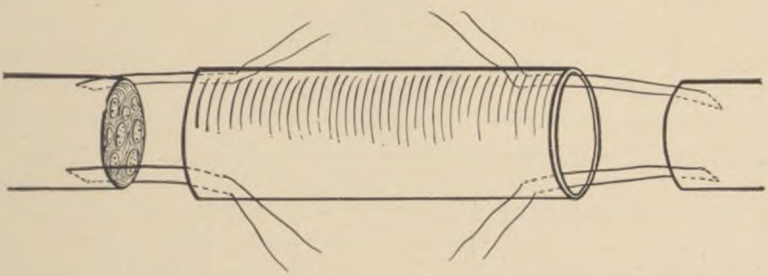

FIG. 71.—ARTERIAL TUBULIZATION.

Two epineural mattress sutures of fine waxed silk are passed at opposite points. Both ends of the suture are threaded and passed through the arterial wall from within out. Sutures must be at opposite points in the tube to prevent the nerve being turned end on against the arterial wall (Stookey).

obtained in autotransplantation as in homotransplantation of nerve segments. The transplant becomes enveloped by connective tissue forming an epineural sheath, and invading strands from the sheath maintain the funicular arrangement of the nerve segments. Downgrowing neuraxes are found penetrating the transplant to reach the distal segment. Experiments were continued by Huber for sufficiently long periods to demonstrate new motor nerve endings in the musculature and evidences of sensory regeneration when defects of mixed nerves were grafted. Slender nerve grafts did not give as good results as "cable" grafts composed of several nerve segments laid together. Heterografting was not followed by as good ultimate results as autografting or homografting. Autografts and homografts of degenerated nerves proved as satisfactory as fresh grafts.

Satisfactory results were also obtained by Huber by the use of autografts surrounded by Cargile membrane previously hardened in alcohol, a method that may be applicable in nerve grafting in fields largely occupied by scar tissue. Similar but less convincing results were seen when nerve grafts were enveloped in formalinized arteries. On the other hand, dense fibrous tissue was laid down when grafts were inclosed in fascial or fat sheaths and the interference with regeneration of the neuraxes led to unsatisfactory results.

Experimenting with homografts preserved in various ways, Huber found no evidence of latent or suspended viability. Petrolatum and 50 per cent alcohol were used, nerve segments being kept for several weeks before transplantation. Satisfactory results were obtained to the extent that downgrowth of neuraxes through the graft took place.

The experimental work of Huber provides considerable latitude in the choice of methods for the introduction of nerve transplantation into clinical surgery, satisfactory results having been obtained by so many different procedures. Heterografts are the least favorable for the purpose. We believe that the use of fresh autografts will prove to be the method of choice whenever a nerve can be sacrificed without harm. It

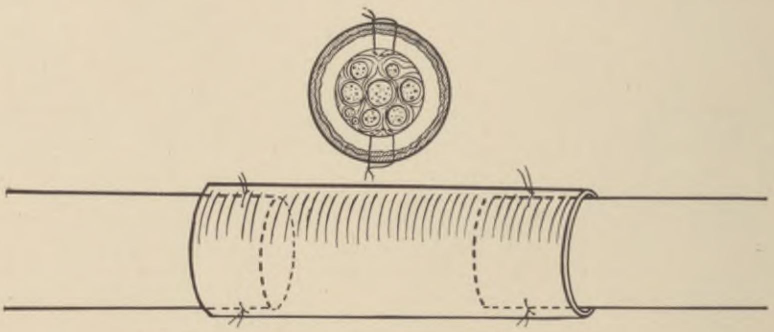

FIG. 72.—ARTERIAL TUBULIZATION COMPLETED.

The dotted lines indicate the nerve ends within the artery. The cross-section shows how the nerve end is held if the sutures are opposite each other in both the nerve and artery (Stookey).

is evident, however, that fresh or preserved homografts offer a wider range of usefulness.

The technic of nerve transplantation involves the same painstaking attention to details and the same delicacy of manipulations so essential to success in the technic of nerve suturing. If experiences in the future establish the clinical value of nerve grafting, it is safe to say that the results will be shown to depend to a greater degree on the technic of operation than on the type of transplant.

The sole indication for nerve transplantation is a defect in an essential nerve too wide to be bridged by other methods. Such defects were frequently encountered during the World War following wounds that had been inflicted by high explosives. Similar lesions that cannot be treated in other ways are rare in civil surgery. The alternative procedures are too well-known to require any detailed description. The method of freeing flaps from the nerve ends to bridge the gap is mentioned only because it was in general use years ago; it is manifestly a harmful procedure. Nerve implantation, in which the stump of the distal segment of the severed nerve is attached to a healthy nerve, cannot be of much value unless some of the nerve bundles of the normal nerve are divided. The dangers inherent in such a step are evident. Nerve stretching in either one or two stages inflicts too much trauma to the nerves to warrant its use. Chief reliance must be placed on free dissection and mobilization of the nerves, whereby gaps, at first sight apparently much too wide for closure, may often be bridged. Mobilization of the nerves with end-to-end suture offers a far greater chance for a successful outcome than any type of nerve transplantation known at the present time. Approximation of the nerve ends can often be aided by transposing the nerves in various ways with the object of shortening the distance between them. Nerve crossing, or nerve transference, is sometimes efficacious when two or more nerves have been injured and the gaps are too great for end-to-end suture.

Clinical Results.—It should be stated at once that a few completely successful results have been obtained after nerve transplantation. Condemnation of the method as one of no proved clinical value is, therefore, unjustifiable. The procedure has been decried by those observers who have seen little or no improvement after it was employed. In view of the existence of successful results, a conclusion that might more properly be drawn is that the outcome is very uncertain after nerve transplantation. Single nerve strands have been used to bridge defects in most of the cases reported in the literature. This fact is of significance, for recent experimental studies indicate clearly that better results may be anticipated with multiple strands or "cables."

The great majority of the cases of nerve grafting in the literature have been reported too soon after operation for an estimation of the final result. Of Sherren's thirty cases, for example, only nine were observed for a year or longer. Improvement was seen in two of these cases and only one of the whole series can be correctly termed a definitely successful transplantation. Similar limited periods of observation are to be noted in the report by Dujarier and Francois, in which the results of transplantation of grafts preserved in liquid paraffin and kept in cold storage were given. Later reports will be necessary to substantiate the promising results that were described. A just estimate of the clinical value of nerve grafting will be possible only when completed reports are made of results obtained after application of the most favorable methods of nerve transplantation.

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CHAPTER VI

THE TRANSPLANTATION OF BONE, CARTILAGE AND JOINTS, AND TEETH

BONE

Of all the tissues used for transplantation none has received so much attention and none has been the subject of such intensive investigation as bone. The literature on the subject has accumulated to such an extent that it is wellnigh impossible critically to sift all that has been written. Even at the present time, great confusion exists as to the fundamental and theoretical principles that underlie bone transplantation. Fortunately this has interfered relatively little with the great strides that have been made in the clinical application of bone grafting for a great variety of purposes. However, in order to appreciate the significance inherent in any bone-grafting operation, it is absolutely essential that an effort be made to learn what happens after bone transplantation. No attempt will be made to describe the work of the innumerable investigators in this field. We will select, and briefly present, the more significant milestones in the development of the subject. Before so doing, let us emphasize the fact that some apparently final conclusions can as yet be only tentatively accepted.

Although the initial work of any importance was begun in 1858 by Ollier, bone transplantation had been attempted many years before that time. Ollier mentions the fact that the idea of bone grafting was of ancient origin, and that efforts had even been made to introduce the method into clinical surgery. He thought, however, that bone transplantation was an undesirable and even dangerous procedure in the human being. In spite of his pessimistic viewpoint as to the clinical application of bone grafting, Ollier's experimental work formed the basis of all future investigations. Above everything else, he established the all-important point that bone could be implanted in the body without being extruded. In his theoretical discussion of bone transplantation, Ollier expressed the opinion that the entire graft remained viable and that the periosteum was of the greatest importance in maintaining the life of the graft. In a classic experiment, Ollier placed the whole metatarsus of one rabbit under the skin of another. Only when the periosteum was left attached to the transplant was there an actual increase in the size of the transplant. This was Ollier's sole test of true healing in place with retention of viability. On the basis of his experimental results, he believed that the only means of obtaining permanent implantation of bone grafts was by the use of living, periosteally covered bone from the same species.

Individual reports of both clinical and experimental successes and failures followed in the wake of Ollier's work. Radzimowsky and Bonome were the forerunners of Barth in indicating that bone transplants, with or without periosteum, present evidence of only temporary viability. The results of Barth's revolutionary work can best be given from his own publication: the graft degenerates in its entirety and becomes replaced by new bone. In other words, its function is in the nature of an osteoconductive scaffold. Hence, living bone, with or without its periosteum, and boiled or macerated bone play the rôle of a dead foreign body. The graft of whatever type, therefore, fulfills only a certain mechanical function when surrounded by living tissue. The source of the new formed bone is not derived from the periosteum or marrow of the transplant but must be from surrounding osteogenetic tissue. . . . Corroboration of Barth's work followed in many subsequent publications by others. In this period a number of clinical reports appeared. A few of the observers supported Ollier wholeheartedly, the viewpoint of others coincided with Barth, but clinical experiences did not, on the whole, establish complete agreement with either. Nevertheless, the general clinical conclusion arrived at was that living bone was superior to dead bone for practical purposes.

It was not until Axhausen, in 1908, announced a middle ground between the two existing extremes that anything new was contributed to the subject. He held that "living" periosteum is essential to the viability of a transplant, that the periosteum does not undergo necrosis in all cases, but that the bone substance itself degenerates, dies, and is replaced. He maintained that, under certain favorable circumstances, the periosteum, in man as well as in animals, remains at least partly viable and that progressive new bone formation is derived from this source. In view of the innumerable misquotations of Axhausen's work that have crept into the literature, it cannot be too strongly emphasized that Axhausen believed that only portions of the periosteum remained viable and proliferated. Furthermore, he maintained that the maximal activity of the periosteum occurred only when the transplant was under a mechanical strain—in other words, when it had a function to perform.

A few years later, Macewen presented an entirely different view of the biologic process after bone grafting. He asserted that the newly formed bone was derived from the proliferation of the osteoblasts of the transplant, and that the rôle of the periosteum was solely that of a living limiting membrane. In short, he believed in a specific function of osteoblasts and that these cells remained alive in the transplant. It appears to us, and has so appeared to others, that Macewen's conclusions were based on ingenuous, but quite erroneously interpreted, experiments.

The results of the little known but painstakingly accurate studies in bone transplantation, conducted by Baschkirzew and Petrow, present a viewpoint on the fate of bone grafts that should, we believe, be generally acceptable. Their conclusions on the whole coincide with the opinions we have held for a long time on the biology of bone transplantation and appear to us, from an analysis of the literature and from our own experience, to be justifiable. They are incorporated, in part, in the following conclusions we have reached on the subject of autotransplantation of bone:

1. Periosteum and bone marrow are not essential for the regeneration of bone in a bone transplant.

2. The chief source of the new-formed bone is the layer of tissue of the host that envelopes the transplant.

3. The liberation of substances from the slowly disintegrating graft constitutes a physicochemical stimulus, resulting in the metaplastic formation of bone tissue from the adjacent connective tissue of the host.

4. The bone cells of the graft die more or less rapidly, depending on their distance from the source of nourishment in the host.

5. Periosteum and endosteum undergo at least partial necrosis. Permanent viability of these layers has not been proved.

6. There is no conclusive evidence that bone is derived from the periosteum or the endosteum of the graft. All the evidence points away from periosteum as a source of bone formation, and this conclusion must be accepted until histologic methods are evolved that will accurately determine the source of all newly formed bone.

7. The periosteum, however, plays an important rôle in bone transplantation. Primary adhesion to the tissues of the host occurring most readily in the presence of periosteum, periosteally covered bone grafts heal in place more promptly. As a corollary, periosteally covered grafts tend to show slower absorption phenomena.

8. The replacement (metaplastic) phenomena in and about a bone graft, characterized by new bone formation, are dependent in large part upon the existence of stress and strain upon the graft.

Homoplastic Bone Grafting.—Homoplastic grafting has not had extensive clinical application. Differences between the sera of two individuals is undoubtedly an important factor in the uncertainty of success attending its use, but this has only been considered theoretically and has not been proved experimentally. Several brilliant clinical successes have been reported with the homotransplantation of bone in various forms. Decalcified homoplastic transplants have been used by some and one very notable result was reported by Kausch with a bone transplant from a leg amputated for trauma. He stripped the transplant of its periosteum and curetted the bone marrow, then boiled it after extraction with alcohol and ether. A tumor of the femur was resected and the graft implanted. Nine months after operation the leg bearing the transplant had to be resected for a recurrence of the original condition (osteosarcoma). The specimen showed perfect union between adjacent bone and graft, newly built periosteum, and an organization and replacement of the implanted bone. In spite of this and other successes, decalcified bone has not usually proved satisfactory for transplantation because of too rapid absorption.

Much more constant have been the successes with bone transplants removed from fresh cadavers or from recently amputated extremities. The best known of these cases is Kuettner's. After resection of the upper third of the femur for chondrosarcoma, he implanted into the defect a whole upper femur, removed from a cadaver thirty-five hours after death. Thirteen months later the patient died of metastases. The specimen showed good union, a newly formed periosteum, and the reattachment of the

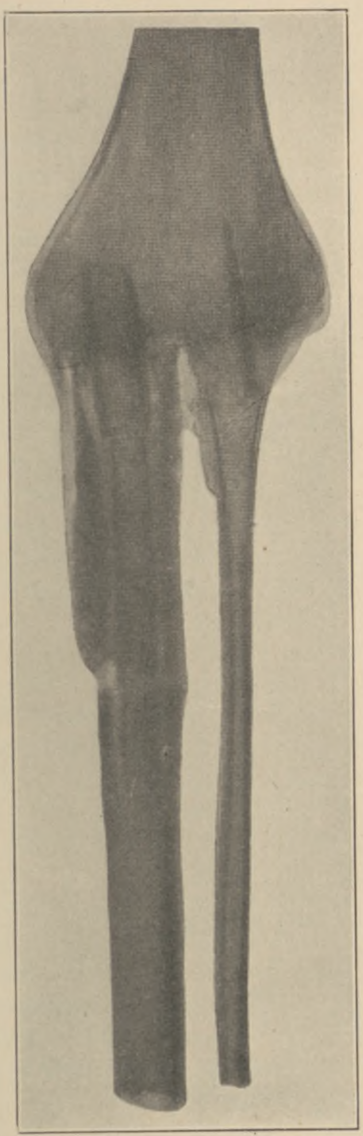

Fig. 73.—X-ray Picture of Specimen after Amputation for Recurrence of Sarcoma.

After resection of the tumor, three-quarters of a year before, a boiled homograft was implanted and fixed with ivory pegs. The specimen shows retention of graft with slow absorption, as well as fusion with adjacent bone (Kausch).

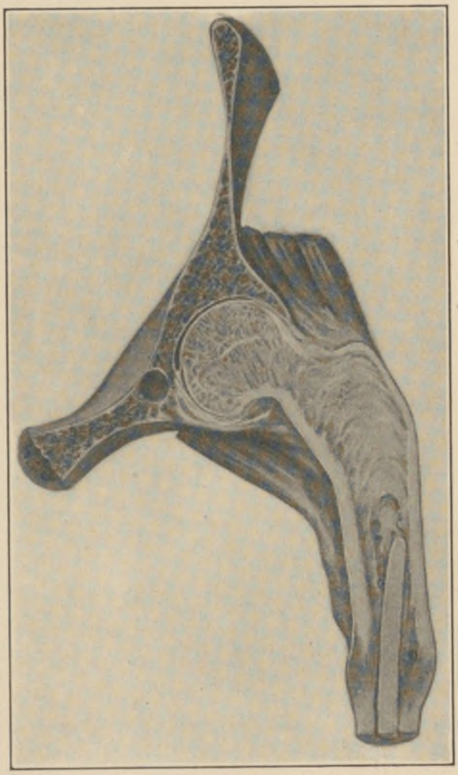

Fig. 74.—Specimen of Transplant of Entire Upper Femur.

Picture taken more than a year after implantation. The patient died of metastases. Retention of contour of graft, fusion with adjacent femur (note ivory peg in place), mobility of hip joint, and attachment of musculature are to be noted (drawing after Kuettner).

musculature to the transplant. The graft stained faintly, showing death of the bone cells with widespread replacement. Similarly, a few observers have described excellent results with the use of bone transplants taken from stillborn babies.

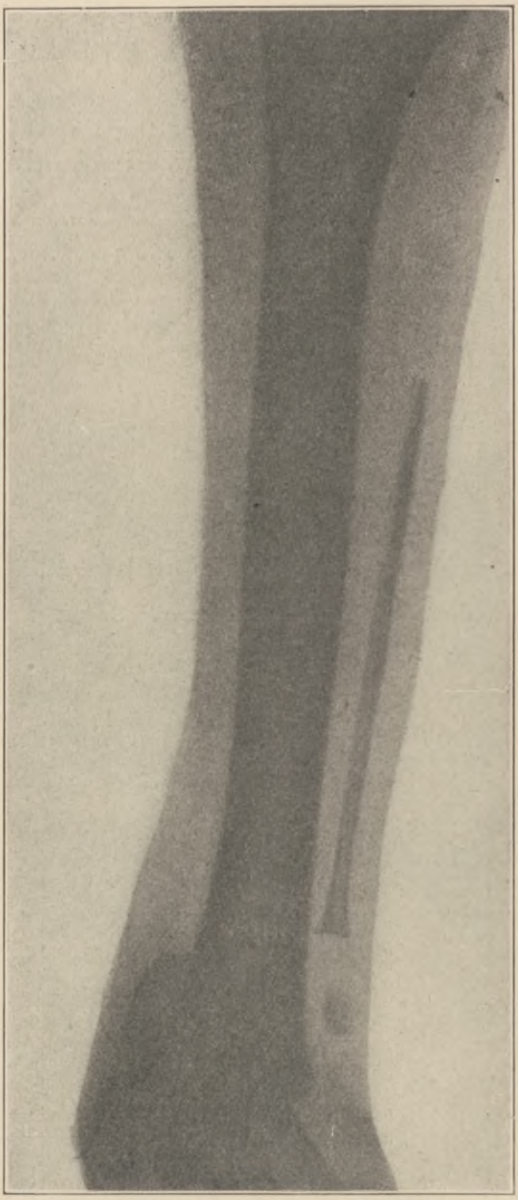

FIG. 75.—IMPLANTATION OF FIBULA FROM AN APE TO A CHILD SUFFERING FROM DEFECT OF THE FIBULA.

X-ray picture taken one year and eight months after the clinical result was satisfactory. Note that the epiphysis as well as the remainder of the graft is sharply outlined (Kuettner).

The number of successes reported after homoplastic bone transplantation suffices to prove some value in the procedure. There are a great many obvious advantages in the use of homoplastic material. Further traumatization of the patient is eliminated, the time of operation is shortened, larger or more suitable grafts may be chosen, etc. To insure the success of homoplastic grafting it was necessary to determine the period of time in which bone remains sterile after death. This was found to be up to eighteen hours.

Homoplastic grafting certainly deserves a more extensive clinical trial than has yet been accorded it. With further evolution of the subject, this method may well prove to be the method of choice in bone transplantation.

Heteroplastic Bone Grafting.—In clinical surgery, bone grafting differs from other tissue transplantations in the fact that a few unquestionable successes have occurred with the use of heteroplastic material. In one case, a splendid functional result, corroborated by X-ray examination six months later, was obtained, the femur of a rabbit having been implanted between the free fragments of an injured femur. Ivory has been used, but the reports of the successes have not been of sufficient detail to be convincing. Bone from sheep, cows, chickens, and other animals has been employed for implantation into human beings, but only a very few of the results can be considered as satisfactory. Kuettner has reported a most remarkable result in the heterotransplantation of bone. He grafted the whole fibula of a Java monkey with its epiphyses into the leg of a child suffering from congenital absence of the fibula. Although histologic examination has not been possible, X-ray pictures taken over a period of several years show permanent preservation of the outline of the monkey's fibula. Replacement by bone must have kept pace with absorption and the sharp delineation of the epiphyses also remains. Kuettner suggested that transplantation from the monkey to the human being is justified, since a close relationship of the bloods of the two has been shown to exist. This relationship follows a definite order—man, orang-utan, gibbon, macacus rhesus, macacus cynomolgus. As regards blood relationship, these tests are said to indicate that man is about as far removed from the orang-utan as the orang-utan from the macacus rhesus. It is possible that, with further studies along these lines, heterotransplantation of bone may be placed on a sound clinical basis.

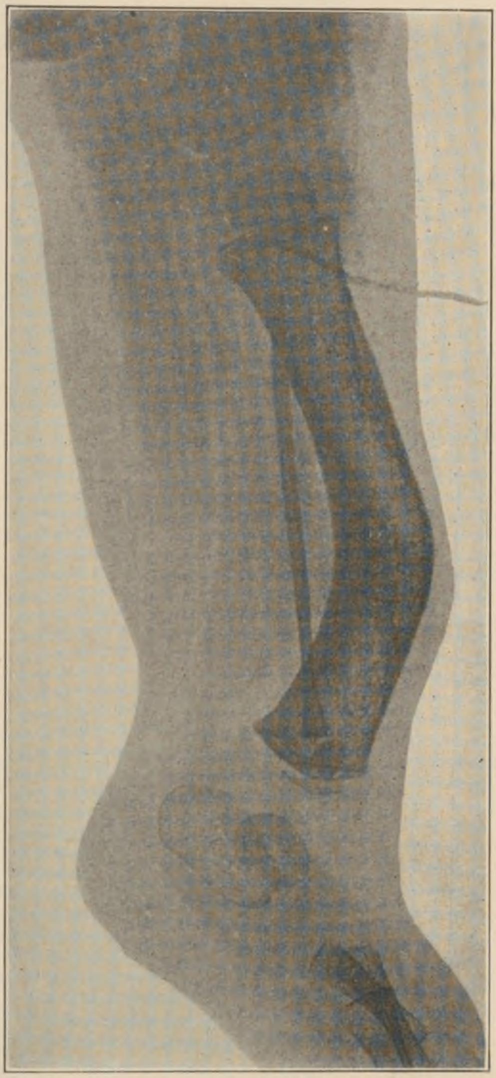

FIG. 76.—THE SAME CASE FIVE AND THREE-FOURTH YEARS AFTER OPERATION.

The contour of the graft from the ape is permanently preserved but it shows no increase in size (Kuettner).

Histologic Changes after Bone Grafting.—Although there has been a great variance of opinion as to the rôle played by the different constituents in a bone transplant, the histologic picture described by almost all investigators has been fairly constant. It is in the interpretation of the findings that the numerous controversies have arisen.

The first union of the transplant with the surrounding tissue occurs by a fibrinous exudate. The latter becomes organized, a layer of new connective tissue being laid down. The phenomena of degeneration of

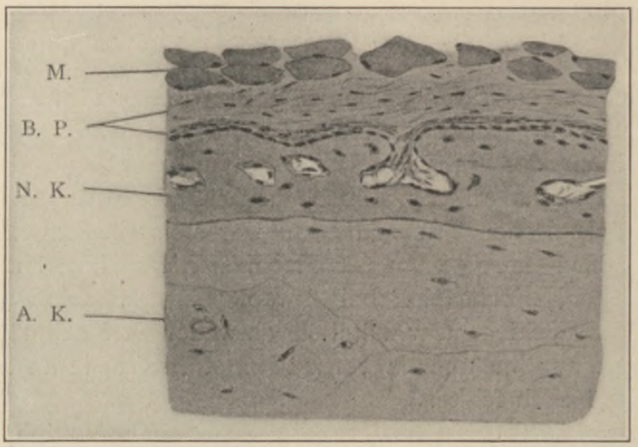

FIG. 77.—CROSS-SECTION OF THE SURFACE OF AN AUTOTRANSPLANT OF BONE WITH ITS PERIOSTEUM.

Picture taken after eleven days. *A, K,* original bone. *N, K,* newly formed osteoid tissue. *B, P,* periosteum and enveloping connective tissue. *M,* muscle (Baschkirzew and Petrow).

the graft and its replacement begin at this early stage. Union of the graft with adjacent bone takes place by means of callus derived from the host. The muscle or other tissues in the vicinity of the transplant

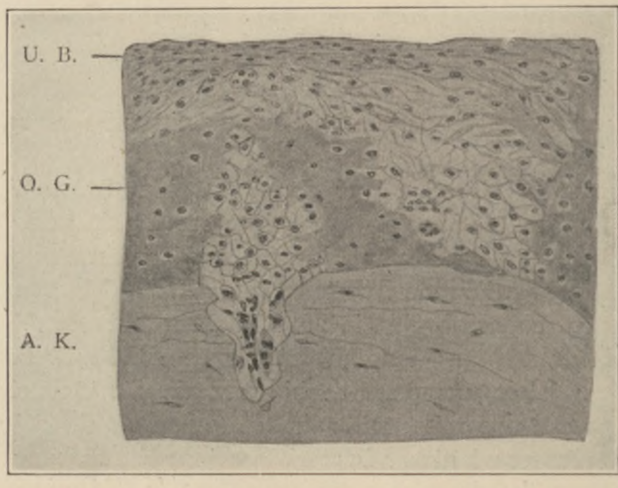

FIG. 78.—CROSS-SECTION OF AN AUTOTRANSPLANT OF BONE WITHOUT PERIOSTEUM.

Picture taken after 10 days. *A, K,* original bone. *O, G,* newly formed osteoid tissue. *U, B,* enveloping connective tissue showing metaplasia into osteoid tissue (Baschkirzew and Petrow).

become rapidly adherent to the surface of the graft, so that the surrounding tissues bear an approximately normal relationship to the bone transplant at the end of about three weeks.

In a periosteally covered transplant an intimate union with the surrounding connective tissue takes place so rapidly that, as early as three

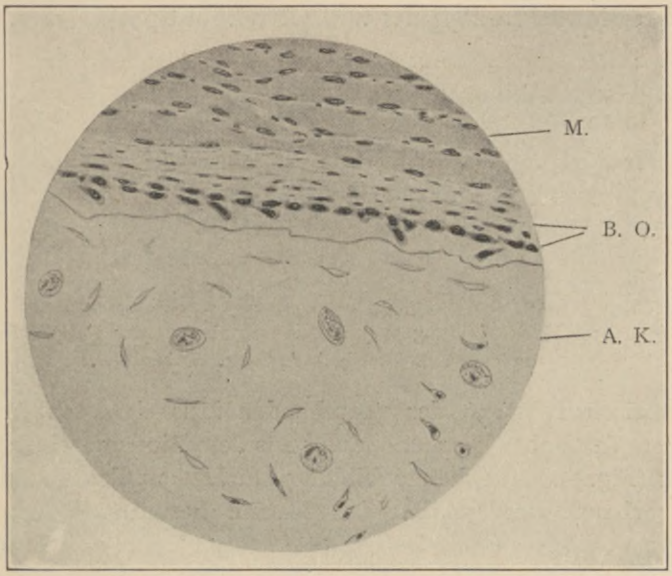

FIG. 79.—AUTOTRANSPLANT OF BONE WITHOUT PERIOSTEUM.

Picture taken after fourteen days. *A*, *K*, bone with cells that are for the most part dead. Haversian canals are occupied by detritus. *B*, *O*, enveloping connective tissue whose fibroblasts are changing into "osteoblasts." *M*, muscle (Baschkirzew and Petrow).

days after transplantation, it is very difficult to separate the periosteum from the surrounding tissue. Blood-vessel injection experiments show

FIG. 80.—AUTOTRANSPLANT OF BONE WITHOUT PERIOSTEUM.

Picture taken after three weeks showing the formation of osseous tissue at the surface of the graft (Baschkirzew and Petrow).

that the layers of the periosteum are freely supplied with blood at the end of two days. In a transplant without periosteum, the union with the surrounding tissue does not occur as rapidly, for vessels cannot be demonstrated in the neighborhood of the transplant at such an early period. After six days, however, no difference can be noted between the vascularization of transplants with or without periosteum. The cells

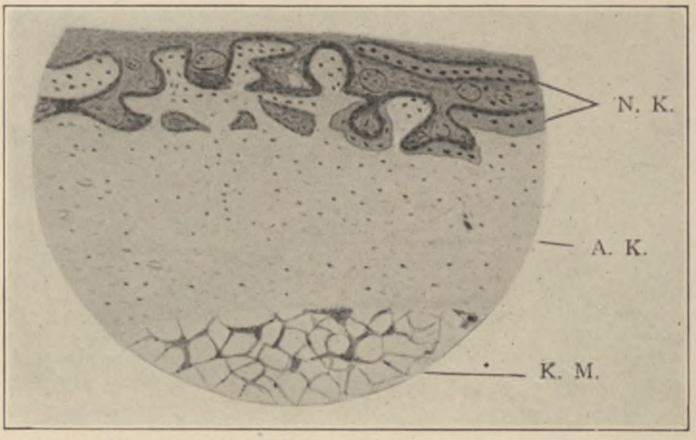

FIG. 81.—AUTOTRANSPLANT OF BONE WITHOUT PERIOSTEUM.

Picture taken after three months showing almost complete regeneration of bone. Note the changes in bone marrow (Baschkirzew and Petrow).

of the periosteum show degenerative processes for the most part. Under exceptional circumstances, isolated islands of cells retain their normal staining properties for a longer time. This fact is believed by some to demonstrate the viability of the periosteum and to indicate that the periosteum is the source of the new bone formation. Experiments

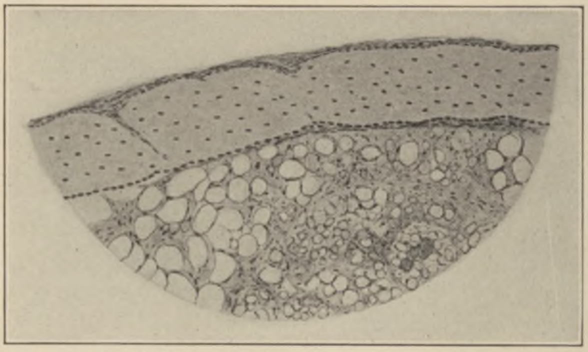

FIG. 82.—AUTOTRANSPLANT OF BONE WITHOUT PERIOSTEUM.

Picture taken after 134 days. Complete regeneration of bone, the wall of which is thin. There are no Haversian canals (Baschkirzew and Petrow).

that have been performed with vital stains have offered no conclusive proof of the viability of the periosteum, because the stained tissue may either be the newly formed tissues of the host adjacent to the periosteum or the periosteum of the graft. Histologic examination has not proved the periosteum to be a source of any new growth of tissue.

The structure and the staining qualities of the graft remain unchanged only a short time. Within a few days the cells begin to show nuclear changes, gradually leading to their disappearance. About three days after transplantation, the nuclei of the bone cells in the central part of the graft present beginning disintegration and degeneration.

Evidence of absorption of the dead bone appears, especially in the form of a lacunar resorption. In the lacunae lay many large, mononucleated cells and wandering cells. The absorption of bone takes place from the surface, from the haversian canals, and from the bone marrow spaces. The bone spaces of the haversian canals are broadened so that the entire bone has a porous appearance. Hand in hand with absorption of bone, the process of substitution of the dead bone by newly laid down osteoid tissue goes on. Connective tissue cells and young blood-vessels invade the bone marrow and haversian canals so that about the eighth day the transplant becomes surrounded and permeated by a richly vascular connective tissue. In some places there

FIG. 83.—COMPLETE CROSS-SECTION THROUGH A PERIOSTEALLY-FREE AUTOTRANSPLANT.

Picture taken after 104 days, showing flattening of the bone with spur formation on both sides (Baschkirzew and Petrow).

are islands of newly formed bone and, in others, the connective tissue shows a marked round-cell infiltration.

Calcification in the loose, richly cellular connective tissues around the blood-vessels begins about the fifth day. From without inward rows of cells characterized as "osteoblasts" appear. Bone lamellae are laid down on the surface of the graft and around the haversian canals and bone formation progresses from these regions. Islands of richly cellular, hyalin cartilage are scattered throughout the transplant. The increase in new bone formation keeps pace with the absorption of the dead bone of the graft.

The vessels of the transplant share the same fate as the osseous portion. Many of the small vessels of the Volkmann's canals are filled with red blood-cell detritus. In the haversian canals and in the mass of the spongy substance are numerous large and small blood-vessels which contain red blood-cells but cannot be injected. Many haversian canals are empty or contain detritus. The connective tissue enveloping the graft is very vascular and the vessels can be readily injected.

The first clear evidence of degeneration of the bone marrow of the graft appears in about one week. The cells lose their nuclei, many are filled with fat droplets, and between the cells are found many polymorphonuclear leukocytes. The blood-vessels in the marrow spaces degenerate and become filled with fibrin, but a few contain some red blood-cells. A connective tissue replacement of the marrow then begins. In four weeks a graft of the diaphysis shows massive fibrous tissue replacement of the marrow; this process is not so extensive in an epiphyseal graft examined after the same period of time. The connective tissue replacing the marrow is very rich in vessels. After a month, the vascularity becomes progressively less and less marked and the tissue becomes less cellular. Regeneration of the myeloid cell elements is seen in the perivascular spaces, and at the end of about five weeks there is

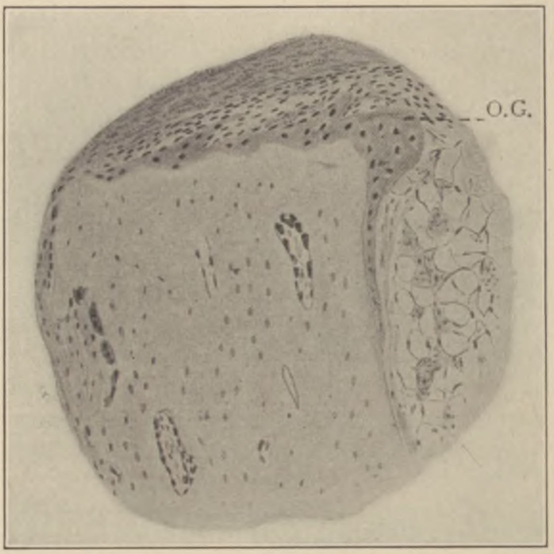

FIG. 84.—LONGITUDINAL SECTION THROUGH THE END OF AN APERIOSTEAL AUTOGRAFT.

Picture taken after fourteen days. Osteoid tissue (*O. G.*) is seen over the cut surface of the transplant where remnants of periosteum could not have been left (Baschkirzew and Petrow).

a richly developed myeloid tissue grouped characteristically around fat-cells. The regenerative process in the marrow is of hematopoietic origin, but whether these new cells are derived from the endothelium or from the adventitia of blood-vessels has not been determined. In view of the histologic changes in the bone marrow, it is fair to assume that death and replacement occur, rather than regeneration from persisting portions of the original marrow.

The cartilage of bone grafts bearing complete epiphyses degenerates more slowly than any of the other elements of the transplant. In the second week, the cartilage cells show beginning changes in their staining reactions. Then an irregular necrosis of the entire epiphysis takes place from without inward. The cells of the subperichondrial layer are thought by some to retain their viability, as they do not show early degenerative changes. The ground substance of the cartilage persists unchanged for some time. Absorption of the dead cartilage about the blood-vessels then occurs. This is followed by the appearance of many new cells that are derived, according to some observers, from the remaining viable cells of the cartilage. The new formed cartilage is ultimately converted into fibrous tissue.

From the histologic findings, it is to be concluded that a bone transplant dies as a whole. Some elements necrose more slowly than others. This varying duration of viability influences the rate of the replacement phenomena and is thus a factor in obviating too rapid absorption of the graft. The clinical importance of this fact is obvious.

General Clinical Indications—*To Correct Deformities Resulting from Lack of Development of the Bones.*—Developmental defects in the bones of the extremities, such as an aplasia of the bones of the extremities, the nasal bones, the mandible, or spina bifida, can be corrected either by free or pedicled grafts, and their treatment varies according to the location and to the extent of the defect.

Nasal deformities, either congenital or acquired, usually require a combined transplant of skin and bone to obtain the desired cosmetic result. For this purpose, a pedicled flap operation has yielded better results. The various procedures that are employed have been previously described (see Chapter II). Free bone grafts are not usually successful in the nose because of infection and should never be attempted if there is a tract communicating with the nasal or frontal sinuses.

To Replace Bone Defects Following Destructive Infections.—Bone cavities following infection, such as osteomyelitis, syphilis or tuberculosis of bone, are usually better treated by other procedures than the transplantation of bone. After sterility of the bone cavity has been secured, such substances as Mosetig-Moorhof paste, or fat implantations may be tried, but the best results have been obtained with sliding flaps of the adjacent skin, fascia, fat, or muscle. The use of bone chips has been advocated as a means of filling bone cavities on the assumption that each fragment of bone is the nucleus of bone production. We now know that this theory is not tenable. Furthermore, the reparative processes are slower than when some other tissue is used and extrusion of some of the bone chips with sinus formation may be the result.

The defects following operations for osteomyelitis generally exist in the form of cavities; if the repair of such cavities is indicated, procedures other than bone transplantation will be found to be more satisfactory. On the other hand, resection of large portions of the shafts of bone for osteomyelitis is a clear indication for bone implantation whenever marked shortening would otherwise occur.

The use of bone transplantation for deformities following tuberculosis of the bone, depends on the locality of the disease and on the nature of the operative measures that had previously been employed. If a resection of the diseased portion of the bone has been performed, no other procedure is as satisfactory as a bone transplant for the replacement of the defect.

For the Repair of Fractures.—The repair of un-united fractures forms the most important clinical field for the application of bone transplantation. The treatment of recent and old fractures must be differentiated. In the former, the operative indication exists, in general, because of inability to approximate or to hold the fragments satisfactorily in place. Nonunion of long standing, on the other hand, may be due to the interposition of soft parts, to the lack of adequate repair because of disease (syphilis), to loss of substance, or to inadequate osteogenesis from unknown causes. An operative technic involving metal plates (Lane), wires, screws, etc., has had a large sphere of usefulness in the treatment of recent fractures but has often failed when applied to old lesions. At best, the introduction of any nonabsorbable foreign material is far from ideal. Atrophy and absorption of the adjacent bone may occur; later removal of the foreign body may be indicated, and the slightest infection may readily invalidate the result. Therefore bone grafting can frequently be used to advantage in the operative treatment of recent fractures. Its greatest application, however, is in the field of old fractures. Here the implanted bone offers a stimulus to osteogenesis that does not follow the use of inert substances. Were this not so, the successes of bone implants, as compared with the other measures that are employed, could not be explained.

Compound fractures, especially those associated with massive loss of bone, were of frequent occurrence in the World War, and limbs that would otherwise have been quite useless were rendered serviceable by bone grafting operations when all other methods failed.

Pseudarthrosis has always presented a difficult problem in treatment. A simple resection of the false joint entails a considerable loss of bone substance. Although the resected ends may be brought together and held by nails or some other contrivance for internal fixation, bone regeneration is very slow and uncertain and marked shortening results. The treatment of pseudarthrosis should include the removal of the false joint, fixation, stimulation of osteogenesis, and the reduction of the amount of shortening. A foreign body, a Lane plate for example, supplies nothing more than temporary fixation. A bone transplant, on the other hand, is not, clinically, a foreign substance. It does not necessitate later removal or invite rarefaction of the bone with which it is in contact, but does, on the contrary, stimulate the osteogenetic reparative processes. A bone graft is, therefore, ideal for the treatment of pseudarthrosis.

To Restore or Replace Fragments Dislodged or Destroyed by Fractures.—In many instances of this sort, such as fracture of the head of the humerus or of the femur, shaft of the tibia, etc., it is possible to use the detached fragment as an autotransplant by replacing it in its correct position and fixing it there. Excellent results have been obtained by this procedure.

To Replace Bone Resected for Benign Neoplasms.—Such lesions as cysts, osteitis fibrosa, adamantinoma of the jaw, etc., may necessitate a complete resection of the tumor-bearing segment of bone in order to secure a thoroughly satisfactory result. Under these circumstances no other procedure compares in effectiveness with bone grafting for the repair of the defect. Some of the best results in the entire field of bone transplantation have been obtained in this type of case.

To Replace Bone Removed for Limited Malignant Disease.—These tumors such as giant cell sarcoma, chondrosarcoma, etc., are sometimes treated by resection, and the large defects that often result may be effectively obliterated with bone transplants. Repair is not adversely affected by the fact that a malignancy has previously existed, for cases are recorded in which consolidation has taken place with a recurrence of a tumor in the transplant itself.

For Immobilization of Joints.—In the treatment of tuberculous arthritis in various localities, such as the spine or sacro-iliac joint, bone grafts have been used to secure immobilization. They have also been used for the fixation of flail-joints following poliomyelitis, for paralytic flail foot, etc. No general statement can as yet be made as to the advisability of bone grafting in this group of cases, although some excellent results have been reported.

Some Special Applications of Bone Grafting—*Skull Defects.*—The repair of skull defects has been a trying surgical problem. The earliest work in the field of bone transplantation was done on skull defects by using heteroplastic grafts; these attempts did not meet with any consistent success. Metal plates of various sorts and ivory plates have been used; the results have rarely been satisfactory. Dead and decalcified bone has been tried, but absorption and fibrosis usually followed.

A tissue transplantation is not ordinarily indicated for the closure of small skull defects. Here a flap operation generally suffices. Of the various procedures, the Koenig-Mueller operation is the most popular. This consists in fashioning a flap of scalp, aponeurosis, pericranium and outer table of skull adjacent to the defect, and sliding it over the prepared area. The gap in the scalp is then covered with Thiersch grafts. A modification of this operation I have employed consists in the detachment of a pedunculated osseopericranial flap, which is then inverted over the defect. When the cosmetic result must be particularly considered, as in lesions of the forehead, the Koenig-Mueller operation is not applicable, and its use should not be attempted for the larger cranial gaps.

Free autoplastic bone grafts have had an extensive clinical trial. The graft is usually taken from the crest of the tibia. On the one hand, large series of satisfactory results have been recorded (for example, Delangenière, ninety-two successes out of ninety-three cases); on the other hand, many failures, consisting in absorption of the transplant and its replacement by nonresistant fibrous tissue, have been described. It appears that the longer the period of observation, the fewer the successes. We have gained the impression that decidedly better results may be obtained by the use of cartilage for the purpose of repairing skull defects.

Inferior Maxilla.—Bone grafting is indicated to replace a defect resulting from infection or from operative interference, or for un-united fracture. Its double purpose is the control of a deformity that would otherwise result from lack of bony substance and to invite solid fixation so that food may be properly masticated. No grafting procedure should be attempted until several weeks after every trace of infection has subsided.

The special feature in transplantation in this region is the question of fixation. It is essential that the lower teeth be maintained in their proper relation to the upper ones and to each other either by an intradental splint or by wiring. The occlusion of the jaws should be maintained until firm union of the transplant to the adjacent bone ends has taken place.

Bone grafting is contra-indicated in the presence of a sinus communicating with the oral cavity, for infection and extrusion of the transplant will almost invariably follow under such circumstances. If the oral cavity has been entered during operation, bone grafting should be deferred.

FIG. 85.—STAGES IN REPAIR AFTER RESECTION OF SPINA VENTOSA AND TIBIAL GRAFT.

Picture taken two weeks after operation (Haas).

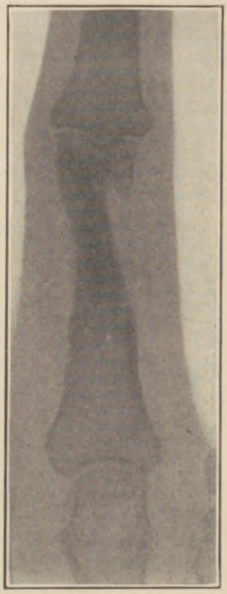

FIG. 86.—SAME CASE AS 85, THREE MONTHS AFTER OPERATION (Haas).

FIG. 87.—SAME CASE AS 85 AND 86, EIGHT MONTHS AFTER OPERATION (Haas).

Spina Ventosa.—Conservative treatment (immobilization) of this condition may be tried but the end result is usually unsatisfactory, shortening and deformity and marked loss of function being the usual sequelae.

Excellent results have been obtained, when the disease has been limited to the diaphysis, by resection of the involved portion of the shaft and implantation of a bone graft. By this method, shortening has to a great degree been obviated and the functional outcome has been satisfactory. The substitution of the whole phalanx of a toe for the diseased phalanx of a finger has been tried. This procedure is more complicated and offers smaller chances of success.

Fracture of the Neck of the Femur.—Fractures of the neck of the femur in the aged are frequently followed by poor results with the ordinary method of treatment. Various operative procedures have been advocated in an attempt to improve and to accelerate repair. A method of bone grafting has recently been devised consisting in the introduction of a bone peg through both fragments after they have been approximated. It is as yet impossible to compare the results of such a procedure with those obtained by conservative methods. It seems reasonable to believe that, repair not occurring with the bone fragments in contact, a better result from bone grafting in the old and debilitated individuals who are the usual victims of this affliction cannot be anticipated.

Old Ununited Fractures of the Patella.—Bone grafting has been made an operative indication for this condition when the ordinary suture methods have not been followed by union of the patellar fragments. We cannot accept this indication for bone grafting, because bony union is by no means essential for a perfect functional result. We have seen a number of cases in which suture of the torn lateral expansions was followed by absolutely normal use of the knee and despite the fact that the fragments of the patella had not united.

Immobilization for Tuberculosis of the Spine.—To secure immobilization of a segment of the spine in Pott's disease, Albee devised a method of fixation by the inlay graft. The spinous processes are split and the graft, removed from the tibia, implanted and sutured in place. The method has been very successful in Albee's hands but similar results have not been so regularly obtained by others. Immobilization in a plaster jacket being simultaneously practiced, it is very difficult to decide to what extent the bone transplant has been responsible for the results obtained. Unless decisive evidence of its value can be presented, the dangers inherent in such an operation (sinuses, tuberculosis in the operative field, meningeal infection) should in general discourage its use.

Deformities of the Foot.—Paralytic flail foot has been treated by Fralten by fixing a graft between the external malleolus and the calcaneum. Inlay grafts between astragalus and scaphoid are also used in paralytic club-foot with good results, according to some observers.

Bone wedges have been successfully employed in the correction of congenital club-foot. The articular cartilages of the astragalus and scaphoid are first removed. Triangular segments of bone are then cut away from the head of the astragalus and the corresponding opposite surface of the scaphoid so as to admit a wedge-shaped bone graft from the tibia. The foot is molded into the corrected posture and the graft is slid into position. Sutures are unnecessary for fixation.

Contra-indications.—The only absolute contra-indication to bone grafting is the presence of infection; in spite of the few successes that have been obtained in the face of mild infections, it is most inadvisable to attempt grafting except in a sterile field. The general contra-indications to any tissue transplantation (Chapter I) apply with particular force to bone transplantation. In other fields, the sacrifice of a tissue and its implantation may entail no harm even if failure occurs. This is not true in general in the field of bone grafting, for a failure may be a disaster and infection in the field from which the graft was removed may be a serious matter. Therefore, the indication for any bone-grafting operation should always be carefully reviewed with these possibilities in mind. Whenever satisfactory results may be anticipated by the use of ordinary surgical measures, bone grafting is contra-indicated.

Technic.—The field for the reception of the graft must be sterile. In open wounds, sterility should be demonstrated by repeated bacteriological examinations. The area from which the graft is to be taken and that into which it is to be implanted are both carefully prepared before operation. Various methods of preparation are employed. We favor a forty-eight-hour preparation whenever feasible. This consists in shaving, the use of a soap poultice, subsequent cleansing with alcohol and ether, and the application of a dry sterile dressing. A weak iodin solution and dry sterile dressing is applied the day before operation. Another iodin application is made at the time of operation.

Most scrupulous asepsis throughout the operation is absolutely essential and for this purpose the Lane technic proves quite satisfactory. Nothing that has been touched by the hand should go into the wound or touch the graft. Gauze wipes should be handled with instruments alone. All sutures should be tied with clamps to avoid touching the suture material with the hands. Instruments once used should be laid aside and reboiled before being used again. Sterile towels should be clamped along the edges of the wound in order to exclude the skin from the operative field. These precautions should be applied in dealing with the site from which the graft is removed as well as to the receiving field.

Active bleeding must be completely controlled and oozing should be checked as far as possible before the graft is implanted (see Chapter I). The interposition of blood-clot interferes with the fusion of the tissues of the host and transplant. Since early union between the graft and the adjacent bone is essential for fixation of the graft, the absolute necessity for hemostasis in bone-graft operations is evident. Furthermore, a hematoma is susceptible to infection, and a suppurative process about the graft is disastrous. A tourniquet should not be employed, and drains are, as a rule, contra-indicated. If the latter must be used, they should be removed as soon as possible after operation and should not be re-inserted. For fixation of the graft, chromic gut, kangaroo tendon, or bone screws should be used and not a nonabsorbable material.

The graft must be sufficiently strong and thick to withstand considerable force, especially in those cases in which it is to be subjected to some strain. Gradual absorption at a later time will render it less resistant than at the time of implantation. However, the diameter of the graft need not approximate that of the bone to be replaced. In the process of replacement and repair, the newly formed bone in and about the transplant will gradually assume the dimensions and contour of the adjacent bone. The length of the graft is determined by the method of implantation that is employed. It is of course essential to have suitable contact between the bone ends of the receiving field and both ends of the graft.

Armamentarium

1. A traction table, such as the Hawley table, is of great assistance in operations on the extremities.
2. Suitable sharp and blunt retractors of various sizes.
3. Bone clamps and bone jacks for bringing the fragments in the desired position.
4. Bone and periosteal elevators.
5. Materials for fixing the graft, such as kangaroo tendon, chromic gut, beef bone screws, etc.
6. Thin-edged osteotome or a sharp chisel, rongeurs, and lion-jaw forceps.
7. Gouges of various widths with long handles; a mallet, preferably of solid steel.
8. Calipers.
9. Plaster of Paris for external immobilization.

Albee has popularized an elaborate, "electro-operative" bone outfit, a slight modification of the Hartley-Kenyon saw. This apparatus is run by a small portable universal motor operated by a foot switch. To the motor is attached a guide handle that may be boiled and that has an automatic catch so that the various cutting and boring instruments may be attached. The cutting instrument consists of a single circular saw or a twin saw. The single saw is about one and one-quarter inches in diameter, with Doyen graduated washers or guards, and is the instrument most commonly used. The twin saw is so constructed that it can be adjusted to any width. It consists of two single saws that can be used singly or together. A dowel or lathe is part of the outfit and can be attached to the guide handle and motor by the automatic catch. The size of the bone graft dowel or nail is regulated by the size of the cutter that is adjusted in the lathe.

The methods of bone transplantation may be considered in several groups.

METHODS EMPLOYED IN BONE GRAFTING

With Temporary Pedicle.—The Reichel operation on the tibia is the best example of this type. For a defect in the tibia a flap of skin with bone is taken from the opposite tibia and the bridge is divided at a second-stage operation.

Free Grafts—*Bone Pegs.*—These are square or rounded sections of bone usually taken from the tibia, and are employed for holding two fractured ends of bone together. Pegs are especially applicable in oblique fractures of the long bones. Two drills are used, one being left

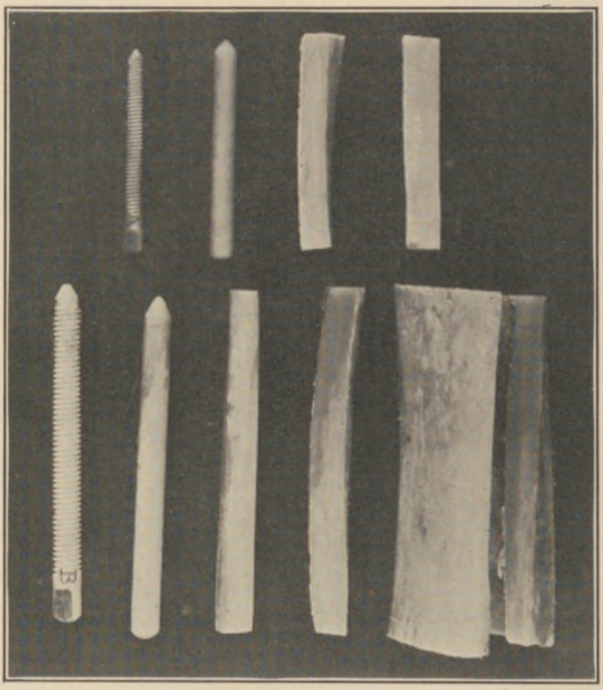

FIG. 88.—VARIETIES OF BEEF-BONE STRIPS OR SCREWS THAT ARE EMPLOYED (Henderson).

in place for fixation when the other is withdrawn. A hole is bored transversely through both fragments and the drill is left in place. With a second drill, another hole is bored through both fragments. The first drill is now withdrawn and a bone peg hammered into place. The second drill is then removed and is likewise replaced by a bone peg. When the pegs have been driven into position, any portion that projects is cut off flush with the bone. Bone pegs are not of great value for purposes of fixation. Beef bone screws accomplish the necessary fixation and, at the same time, obviate the necessity of cutting and shaping peg grafts.

Osteoperiosteal Methods.—Codivilla's operation is an autoplasty by means of periosteal flaps. It is closely allied to the transplantation of pedunculated flaps of bone. The ends of the bone are freshened and are then united by a wire suture. The latter is enveloped in a detached flap of periosteum taken from any convenient bone. Codivilla is careful to remove a thin shell of bone with the periosteum. The periosteal sheets are from 3 to 4 mm. in thickness and are made long enough so that they can be fixed to each fragment by two sutures about 1 cm. apart. The method can be applied only where there is a loss of substance no greater than a few centimeters.

Concerning this method it appears to us that when wiring suffices for the purpose, nothing need be added. If a bone graft is required, one of the methods described below, involving the use of massive grafts, is more desirable than thin osteoperiosteal sheets. In transplanting bone, there should always be sufficient material to offer reasonable assurance that the graft will serve a really serviceable purpose.

Delangenière also advocates transplanting osteoperiosteal grafts taken from the tibia for the repair of loss of bony substance. The graft is obtained by removing thin layers of bone with its periosteum by means of a sharp, bevel-edged (engraver's) chisel and a hammer or mallet.

The tibia is exposed, care being taken to avoid injury to the periosteum. The graft is then outlined with a scalpel. The size of the graft is determined by the defect to be covered. The chisel is held almost vertically with the cutting edge firmly pressed against the bone. By varying the inclination, sheets of bone with periosteum, a few millimeters thick, may be detached. When the graft is removed, it is placed in a gauze compress and is then, without delay, transplanted into the wound that had previously been carefully prepared for its reception. By using several thin sheets and overlapping them the defect is closed. The grafts are held in place by sutures.

Remarkable results have been claimed for this method by Delangenière in all varieties of conditions in which bone transplantation is indicated. Reference has already been made to the probable outcome of such bone transplants in the repair of cranial defects. Concerning its use elsewhere, we think that, in general, the remarks made in connection with Codivilla's method apply with equal force to Delangenière's procedure.

End-to-end Operation.—The Hahn-Huntington operation, or some modification of it, is the best procedure in this type of grafting. It consists in a two-stage transplantation of the fibula into a tibial defect. The lower end of the fibula is first united to the lower end of the tibia beyond the defect; a few weeks later the upper end of the fibula is transferred to the proximal end of the tibia. This method is only applicable in tibial lesions, but has proved of real service even in cases in which extensive loss of bone substance existed.

Albee's Inlay Method.—The fracture is exposed by a generous incision. The skin and subcutaneous tissues are retracted, and the bone ends are freshened with chisel, motor burr, or saw. If there is overlapping of the fragments and extension and traction cannot completely reduce the fracture, it may be necessary to trim the fragments until good position is secured. Shortening will result, but this cannot be avoided under such circumstances. After reduction, the fragments are held in correct alignment by a clamp of the Lane or Heitz-Boyer type. The periosteum is incised longitudinally over the bone ends where the section of bone is to be removed for the insertion of the inlay. The periosteal flaps are turned back on either side, exposing the bone. Two parallel saw cuts, about three-eighths to one-half an inch apart, are made in the long axis of the bone and are carried completely through the bone cortex to the marrow cavity. A chisel or a twin circular saw may be used for the purpose. These cuts are made from two and one-half to three inches into the end of each fragment while the bone ends are being held in the desired position. The bone cuts should always extend far enough from the line of fracture to reach normal, nonsclerosed bone of both fragments. This distance is, of course, subject to considerable variation.

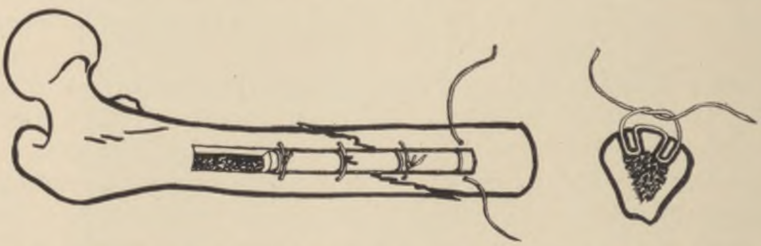

Fig. 89.—Diagram to Illustrate the Technic of the Sliding Bone Graft.

The method for fixation of the wedge-shaped graft by Kangaroo tendon sutures is shown in the cross-section.

After the twin saws have traveled the desired length to make the gutter for the graft, the bone strips between the saw cuts are removed by joining the far ends with a narrow osteotome. These chisel cuts are made V-shaped so that a tongue and groove joint with the ends of the graft will be obtained. If sutures are to be used, holes are bored in the cortex on each side of the gutter, and are directed inward, towards the marrow cavity. These perforations are placed near the bone ends in order that the central portion of the inlay can be fixed. The ends of the graft are secured in position by the tongue and groove joint, when feasible, or by additional sutures. This joint is so made that the greater the muscular contraction, the more securely the graft is held in place.

The exact length of the bone inlay is determined by measuring the gutter and transferring the marked measure to the exposed antero-internal aspect of the opposite tibia. A flexible probe or calipers answers this purpose, a right-angled bend in the probe indicating the exact measurement.

The wound is packed with hot saline compresses while the graft is being removed. The tibia from which the graft is to be taken is exposed by an incision over its crest. The soft parts are retracted, and the size and shape of the graft are outlined in the periosteum with the probe as a guide. The bone is then cut down to the marrow along the outlines marked on the tibia. The ends of the graft are then appropriately shaped to fit into the prepared gutter and the graft is transferred to its bed.

A double strand of heavy kangaroo tendon is passed through the drill holes that had been made. One of the strands bridging the gutter is elevated and one end of the graft is placed between the two strands. Traction is now exerted on the limb and the other end of the graft is slipped into position and fixed by the sutures in the same way. With the release of traction, the tongue and grooved ends come into tighter adjustment. The kangaroo tendon sutures are then drawn taut and tied over the graft. The site of the fracture is covered with the periosteal flaps that had been reflected. The overlying tissues and skin are closed without drainage. The incision over the tibia is closed in a similar way, except that the edge of the muscle is drawn into the cavity from which the graft was taken. After a suitable dressing, plaster of Paris is then applied to immobilize the fractured region and the adjacent joints.

This method is a refinement of the ordinary procedures that have been employed to implant a thick bone graft. We have, therefore, described it in detail to the exclusion of the other methods that have been practiced. The implantation of a thick osteoperiosteal graft from the tibia offers the best method for bone transplantation in the repair of un-united fractures of long standing.

Sliding Grafts.—These grafts are taken from the fragments themselves. This is best done by making the saw cuts in one fragment just double the length of the other and transposing the two strips of bone that are detached. The grafts are removed from the bone ends by motor saw or chisel and consist of a section through the cortex into the marrow cavity. The longer strip is then inserted into the gutter so that half of it lies across one fragment and half across the other. The inlay grafts should be wedge-shaped, so that they are about a quarter of an inch wider at their periosteal than at their endosteal surfaces. Wedge shaping of the graft and the gutter prevents the transplant from slipping into the marrow cavity. The grafts are held in place by autogenous dowel grafts placed obliquely into the cortical bone on either side of the gutter, with their ends projecting over and in contact with the periosteal surface of the graft.

This method should be employed wherever possible, as it has all the advantages of the inlay operation and, in addition, spares the tibia. It is applicable (1) when a bone graft is indicated in the operative treatment of a recent fracture; (2) when a short resection of a long bone has been done and the fragments are not widely separated; or (3) after resection of a pseudarthrosis when the resultant gap is not large.

Fixation by Intramedullary Pegs.—The ends of the bone are freshened.

The marrow cavities of the upper and lower fragments are enlarged by a reamer or a burr for a distance sufficient to form a firm bed for the implant. The tibia is exposed by a longitudinal incision through the tibialis anticus muscle. The upper and lower limits of the desired transplant are marked and a graft from one-half to three-quarters of an inch in diameter is removed. The wound is closed by deep and superficial sutures. The ends of the bone to be grafted are exposed. The limb is bent so that the lower fragment is easily accessible. The tibial peg is driven lightly into the medullary cavity for a distance of one to one and one-half inches. The limb is then manipulated so that the end of the peg protruding from the lower fragment enters the medullary cavity of the upper fragment. It is sometimes necessary to drill transversely through the receiving bone and the implant, and to pass a kangaroo tendon suture to further insure the fixation of the graft. This operation is applicable in cases in which considerable tension on the graft may be anticipated.

Where the end of a bone with its articular surface is to be replaced by a similar joint-bearing bone graft, the best procedure is to shape the end of the transplant as a peg and drive it into the medullary cavity of the end of the bone receiving the graft, securing it with sutures if necessary.

Homoplasty.—The only special feature to be considered in the technic of homoplastic grafting is the collection of the material. The bone graft is preferably taken from a young individual, immediately after death from accident, or is obtained from a recent amputation. It is, of course, essential to determine that the donor is free from the lesions of syphilis or tuberculosis. The graft must be removed within as short a time as possible after death, because a general bacterial invasion may begin not long after the time of death. From what has been said on the relationship of blood groups to tissue transplantation, it would seem desirable to seek a donor whose blood is compatible with that of the recipient when this is possible. Some observers have demonstrated that the graft may be boiled or preserved in salt solution, to which an antiseptic is added, and successfully used. Dead bone, however, does not seem to give as good results as living grafts because of too rapid absorption. All the precautions in asepsis described in autoplastic technic must be observed in removing the graft if it is not to be boiled or decalcified.

Heteroplasty.—Beef bone screws are the only heteroplastic material that are ordinarily employed in bone grafting. Although only recently introduced, they have already assumed an important place in operations for fractures and in fixing bone grafts.

For heteroplasty, either living, dead, or decalcified bone may be used. Living bone from an animal closely related to man, as the monkey, appears preferable. It seems that the farther removed the species are from each other, the less the chances of success in heteroplastic grafting. The technic differs in no way from that described for autoplasty.

Homoplasties and heteroplasties make possible the use of large grafts with their joint surfaces. Such procedures as replacing the head of a bone with its shaft or substituting an entire shaft, obviously not feasible by autoplasty, can be practiced. It is to be hoped that with further studies in the transplantation of tissues, homotransplantation and even heterotransplantation of bone may become practical procedures that will meet with consistent success.

The *after treatment* of bone-grafting operations consists in immobilization in plaster of Paris, through which a window may be made over the site of the wound. The time for removal of the cast and for mobilization varies, depending on the nature of the operation and the condition for which the operation was performed. Repeated X-ray examinations are of great value in determining when it is safe to discontinue fixation and to begin motion.

Résumé of the Biology and Clinical Value.—In closing this chapter we must indicate again that a considerable difference of opinion still

Fig. 90.—Bone Formation Two and a Half Months after Fat Graft into a Defect of the Bladder.

The break in the overlying epithelium is an artefact.

exists as to the phenomena that occur when bone is transplanted. It appears difficult to disregard time-honored work even when later studies demonstrate errors and inaccuracies in observation. The flaws in many of the older and in some of the more recent studies will have to be clearly recognized, however, if further progress is to be made in this field. The evidence we have indicates the ultimate death of the entire bone graft. Replacement phenomena, terminating in the formation of new bone, occur chiefly when the graft is placed in contact with the bone of the host and is subject to stress and strain. Such replacement phenomena are not likely to occur in the absence of these mechanical factors. The osseous tissue appearing in the neighborhood of the graft is partly derived from the bone of the host but to a greater degree by metaplasia of the undifferentiated connective tissue extending into and enveloping the transplant. Thus cartilage and bone may be laid down in and about grafts other than bone, fascia for example, under certain circumstances. Substances, presumably physicochemical agents, re-

FIG. 91.—AN ILLUSTRATION OF METAPLASIA AS NOTED TWO MONTHS AFTER THE TRANSPLANTATION OF FASCIA INTO A DEFECT OF THE BLADDER.

A plaque of true bone, *B*, *B*, occupies the site of the defect. Cartilage, *C*, as well as bone marrow present the evidences of active growth.

leased by the disintegrating transplant appear to stimulate the formation of new bone. Proof is lacking that there exists a specific bone-forming cell termed the osteoblast.

No single element of a bone graft is essential for successful transplantation. The endosteum and bone marrow are of minor importance; in fact, there is some evidence that bone marrow transplanted with bone invites an undesirable reaction in the host, and its removal from the transplant has been advocated. Persistent viability, osteogenetic powers, or other functions peculiar to periosteum have not been proved. The practical importance of transplanting overlying periosteum with bone lies in the fact that early union of the graft with the surrounding tissues occurs, and the process of orderly replacement of the transplant by bone is thereby invited.

A clinically successful result depends upon the persistence of the graft until its adequate replacement by the host takes place. Consistent results are not obtainable by the use of dead grafts. Maximal success in bone grafting is to be had at the present time only by autotransplantation of living, periosteum-covered bone. Homotransplantation has a lesser degree of success and heterotransplantation least of all. At the same time one of the most brilliant clinical results and one of longest duration in the whole realm of bone grafting was obtained by Kuettner in his case of replacement of the upper femur with its articular surface by the femur of a monkey. This aspect of the subject calls for more intensive work, based on our present-day knowledge of blood and tissue compatibility; for successful homotransplantation and heterotransplantation of bone of course manifestly approach the ideal more nearly than autografting.

Follow-up reports are on the whole sadly lacking in the history of bone grafting. Until the ultimate results in large series of cases are known, definite statements of the clinical value of bone grafting can not be made. It is safe to say that the method is of great aid in a variety of conditions and has solved many difficult surgical problems that otherwise would have been hopeless. This is not enough, however, for a knowledge of the proportion of successes as compared with failures is imperative for a true evaluation.

Rigid asepsis, a satisfactory technic of operation, and proper immobilization after operation are prime factors in obtaining satisfactory results. However, it is only when they are combined with the correct indication for bone transplantation that a clinical success may be anticipated with assurance. The clinical value of bone grafting will be greatly enhanced by reserving the procedure for situations in which it is really indicated, and by employing ordinary surgical methods when they can satisfactorily meet the conditions that exist.

CARTILAGE AND JOINTS

The subject of transplantation of cartilage has not received the attention that has been given to other tissue transplants. It has usually been studied merely as one phase of bone transplantation. Joint and cartilage transplantation are so closely allied that they may be discussed together.

Paul Bert is properly accredited with being the first to transplant cartilage. From his experimental studies he came to the conclusion that a cartilage graft retained its viability and led to the formation of bone. Not long after, Zahn assumed a diametrically opposed view of the fate of adult cartilage transplants, also basing his observations on experimental results. He noted degenerative phenomena in the graft that ultimately led to its absorption, regardless of the locality to which it was transplanted. However, his later experiments with fetal cartilage yielded different results. The transplanted cartilage increased in size, but the amount of growth was variable, which he thought due to a difference in the vascularity of the bed in which the graft was laid. Leopold, following Zahn's lead, transplanted fetal cartilage into the abdomen with similar results. The proliferation of the cartilage cells in some experiments was followed by ossification, while in others voluminous tumors developed. On the other hand, adult cartilage was rapidly absorbed.

The later development of conflicting views on the outcome of experimental transplantation of cartilage may be briefly sketched. Fischer is responsible for the origin of the theory that the survival of a cartilaginous graft is dependent on the presence of the perichondrium. In his experiments, costal cartilage degenerated when transplanted without its perichondrium, the ground substance became fissured, and the entire graft was vascularized after eight weeks. Cartilage transplanted with its perichondrium showed no alterations in structure in the same period. The *epiphyseal cartilage* was reimplanted in experiments conducted by Helfferich. Microscopic examination showed central degeneration but the cellular structure near the surface of the graft was well maintained and mitotic figures were present in the cells beneath the perichondrium. These peripheral, surviving areas became ossified according to Helfferich. On the basis of these findings he believed that transplanted epiphyseal cartilage maintained its property of producing a growth of the length of bone under favorable circumstances. Ollier and also Tizzoni, at a later date, established the fact that articular cartilage when transplanted subcutaneously rapidly degenerated, and, as a consequence, believed that degeneration was inevitable in the absence of nourishment by synovial fluid. In 1904, Seggel made the first systematic histologic studies of cartilage transplants in an effort to determine their fate. He noted the gradual death of the graft and its substitution by bone, although ossification was not complete at the end of eighty days. Good functional results were obtained by Zoppi in autotransplantation of epiphyseal cartilage, but attempts at heteroplastic grafting were failures; while Gallarzi found that, in both autotransplantation and homotransplantation of epiphyses, calcification of the cartilage occurred with complete loss of function. About this time the first clinical report of cartilage transplantation appeared. Tuffier described a procedure, characterized as chrondroplasty, in which he reimplanted the head of the humerus with its articular surface after resection of the upper end of the humerus. He anticipated that the presence of the smooth articular cartilage would prevent ankylosis. The functional result was excellent but the persistence of the cartilage as such was not demonstrated.

Judet, on the basis of extensive experimentation with articular cartilage and joint transplantation, attempted to prove that the success of such transplantations depended entirely on the presence of the synovial membrane. He also maintained that heteroplasties might be successful if the synovial membrane was left undisturbed.

In the more recent work on *epiphyseal transplantation,* only Rehn and Wabakayashi and von Tappeiner express the opinion that both autografts and homografts fully maintain their histologic structure and function after transplantation. Axhausen's studies conclusively established a gradual degeneration of the epiphysis; other than a slight proliferation of the remaining cells near the periphery of the graft, the entire epiphyseal line was replaced by fibrous tissue. The work of other investigators has also demonstrated that the epiphyseal cartilage ceases to function after transplantation, longitudinal growth of bone being arrested. For the main part, the cartilage degenerates and is either converted into fibrous tissue or is ossified. The only evidence of regeneration is seen near the periphery, beneath the perichondrium, where new cartilage is laid down that, at a later period, becomes calcified. Similar changes occur when articular cartilage is transplanted, but the changes are followed by regeneration of the cartilage with only partial fibrous replacement. Very few experimental observations have been made on *joint transplantation.* In Judet's pioneer work, whole joints were transplanted subcutaneously and only slight retrogressive changes were found after many months' observations. He showed that the intact synovial membrane was necessary for the retention of the joint structure. Lacking synovia, disintegration and fibrous replacement of the ends of the bones characterized the changes that occurred.

The first clinical application of joint transplantation occurred in 1907. Lexer, after the resection of the upper third of the tibia with its articular surface for sarcoma, transplanted a similar portion of tibia that he removed from a freshly amputated limb. Then followed reports of successes with half-joint transplantations by Kuettner, Rovsing, Wolff, Enderlen, and others. Kuettner obtained his material from fresh cadavers and in one remarkable case, previously mentioned, the transplant was obtained from an ape. Lexer advised the use of material from freshly amputated limbs or from individuals who died of injuries. His objection to using joints from cadavers was the difficulty in obtaining sterile grafts and because fibrous encapsulation occurred in one instance.

Autoplasty is applicable only in the replacement of finger joints as a rule, joints from the foot being used for this purpose. The only other source of autoplastic material is the fibula, the upper end of which has been utilized successfully by Walther and others to replace the lower end of the radius. Autoplastic transplantation of a complete long bone is practicable only in one situation—the transference of a phalanx or metatarsal bone from the foot to the hand.

The reimplantation of half a joint is sometimes a useful procedure in operations for fracture dislocation, especially of the head of the humerus. Some excellent results from this procedure have been reported since the early successes of Lexer, Perthes, and von Haberer.

Up to the present time, *whole joint transplantation* has had very little clinical application. Except for the experience of Lexer in this field, there is no work worthy of mention. The best known of his cases is that in which he resected the knee-joint of a girl twenty years old and

FIG. 92.—THE DEGREE OF ACTIVE FLEXION.

Picture taken one and one-half years after implantation of a whole knee joint following resection for ankylosis (Lexer).

FIG. 93.—THE DEGREE OF PASSIVE EXTENSION IN LEXER'S CASE OF JOINT TRANSPLANTATION

replaced it by a homograft from a freshly amputated limb. The case was reported six years after operation and presented a number of interesting features. Clinically permanent healing had occurred. The X-ray examination showed changes, due to absorption and excessive growth at the site of union between graft and host, similar to those occurring in arthritis deformans, motion and function being free within a rather limited range but sufficient for locomotion. After several other attempts at transplantation of the whole knee-joint, some of which were successful to a degree, Lexer concluded that the greatest postoperative difficulty following transplantation lay in the restoration of the function of severely damaged extensor muscles. These muscles with their tendons are often destroyed by intercurrent suppuration. It is found that they have become atrophic or have undergone fatty degeneration because of ankylosis existing for long periods. Other complications encountered were fluid exudates into the transplanted joint, fibrous encapsulation, and later changes presenting a picture similar to that seen in arthritis deformans. Any of these complications may result in impairment of function. Only passive motion may be possible in some cases, or active flexion and extension may be greatly restricted. In cases in which the musculature is well preserved, function is naturally more satisfactory than in those in which operations must be performed in an effort to restore active motion.

Experimentally, it is extremely trying to perform whole-joint transplantation on small animals, since the transplant is readily injured by the necessary manipulations and especially because complete hemostasis and adequate postoperative treatment are difficult of accomplishment. The results of the experiments cannot be readily evaluated. Nevertheless, the possibility of successful transplantation of joints in man as well as in animals has been established, the various elements of the graft undergoing slow changes that may be followed by a satisfactory regeneration of the parts. It is not necessary to have replacement of articular cartilage by cartilage in order to obtain a satisfactory functional result.

Histologic Changes—*Simple Cartilage Grafts.*—In the first two days after transplantation, a pronounced fatty degeneration is noted in the perichondrial cells but no other changes are seen. The outer layers of the perichondrium then degenerate and are replaced by new connective tissue from the host, while the inner layer next to the cartilage is unchanged. The hyalin matrix remains unaltered in appearance and in staining reaction for many weeks; only in grafts that are several months old does fibrillation of the cartilage begin. A finely granular calcification occurs at a still later period. There is a gradual death of the cartilage cells and they ultimately disappear. Vascularization of the graft and replacement by fibrous tissue or calcification may occur, depending on the locality to which the graft is transplanted. The outstanding feature in the histologic fate of cartilage transplants is the long period of quiescence that precedes the final phase of degeneration and substitution.

Epiphyseal Grafts.—The earliest changes in the graft of an epiphysis are to be seen in the marrow. A widespread necrosis occurs in the latter within a few days. Fibrous tissue replacement then takes place, to be followed by a regeneration of the marrow, hemopoeitic in origin. The first evidences of degeneration in the epiphyseal cartilage are not usually manifest until towards the end of the first month. About that time, a cleavage line is seen that extends through the cartilage columns. This is followed by progressive degeneration. There is a decrease of the number of cells in the perichondrium, the nuclei disappear entirely or stain faintly, and the homogeneous ground substance begins to break up. The cartilage becomes macerated, the cells degenerate, and cavities are formed to become filled later with granulation tissue. The only sign of regeneration is near the periphery, beneath the perichondrium, where mitotic figures are occasionally observed and some new cartilage

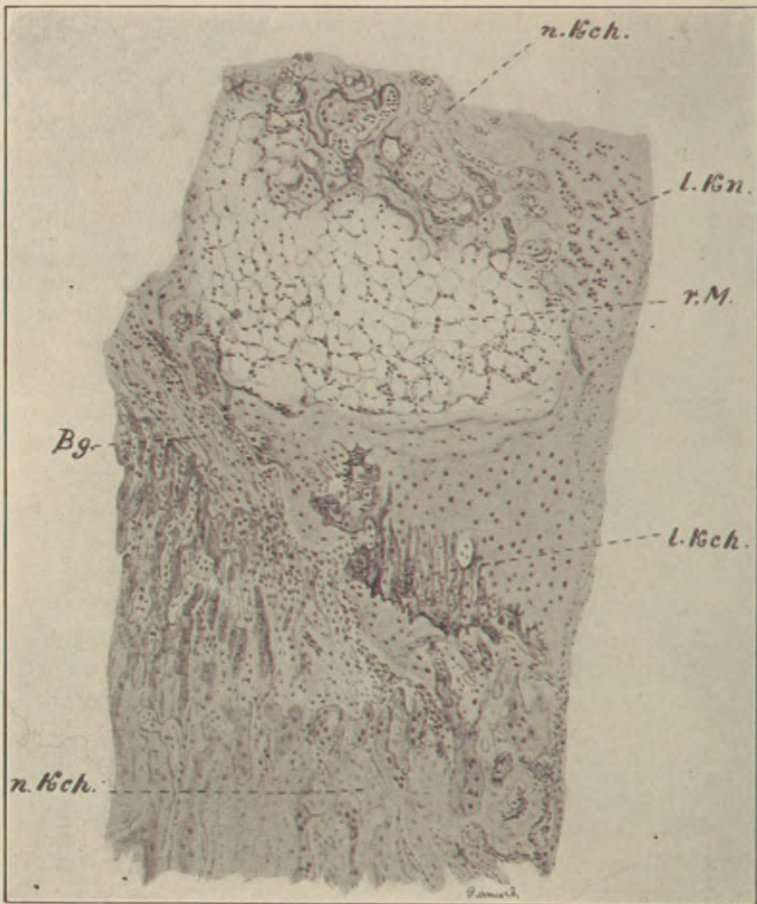

FIG. 94.—END OF THE FEMUR OF A RAT ONE HUNDRED DAYS AFTER TRANSPLANTATION.

The transplanted bone (*n. Kch.*) is necrotic. The joint cartilage (*l. Kn.*) is viable. Complete regeneration of bone marrow (*r. M.*). The epiphyseal cartilage has been replaced by connective tissue for the most part (*Bg.*) and to a lesser degree by bone (*l. Kch.*) (Axhausen).

is laid down. This process of regeneration is very limited, however, and the newly formed cartilage is soon ossified. The dead cartilage finally becomes replaced by a fibrous tissue that may persist as such or become ossified.

The bone cells of the osseous portion of an epiphyseal graft lose their staining properties shortly after transplantation. The trabeculae then show further degenerative changes and are converted for the greater part into a homogeneous noncellular tissue. Evidences of regeneration appear later in the form of bone deposition around the homogeneous central portion, ultimately leading to the complete reformation of the trabeculae in many cases. The epiphyseal line is entirely gone at the end of two months, being replaced by fibrous tissue with a few small remnants of irregularly arranged cartilage. Ossification may occur at the site of the epiphyseal line, but this is an inconstant feature of the picture.

Of all the components of bone, the epiphyseal cartilage is the least transplantable and under no circumstances does it maintain its special function of producing growth in length of bone after transplantation.

Articular Grafts.—The usual processes of degeneration and replacement occur in the osseous elements and in the marrow near the joint. The alterations in the articular cartilage take place very slowly. The earliest changes occur in the deeper layers of the cartilage, which undergo typical degeneration and fibrous replacement. After a considerable period of time, degenerative changes are also seen in the superficial layers of the cartilage. Although fibrous tissue replacement may persist in scattered areas, there is, on the whole, a regeneration of the articular cartilage. The regeneration of cartilage is thought by many observers to be derived from cartilage cells retaining their viability. We believe, however, that it is the outcome of a metaplastic differentiation of the growing connective tissue of the host, the evidence pointing to the death of the graft. The capsule of a transplanted joint disappears soon after transplantation.

The changes that are seen in a transplanted joint after a period of years simulate closely those occurring in arthritis deformans. The alterations in the articular graft occasionally lead to undesirable sequelae such as gradual absorption, encapsulation, or organization by fibrous tissue.

Clinical Application.—In *plastic surgery,* especially that of the nose and ear, the transplantation of cartilage has yielded brilliant results. In the treatment of deformities of the ear or the nose, it is not infrequently necessary to use a graft that has skin on both sides. The important requirement is a satisfactory and enduring support of the skin flap. A cartilage graft answers this purpose better than any other tissue transplant. It heals in place without reaction, is sufficiently rigid to give support, and can be shaped for the desired purpose. Most important is the fact that changes occur very slowly in the transplanted cartilage, and its shape and contour are maintained over very long periods of time. For this latter reason and because of its pliability, cartilage is preferable to bone. Fat, the only other tissue that has been employed for the purpose, does not give the required support and undergoes shrinkage within a fairly short time. The most convenient source of the cartilage graft is the costal cartilage. As a rule plastic operations involving its use are performed in two stages. The first consists in the transplantation of cartilage beneath the skin for a period of about a week, in which time the graft has healed in place. In the second stage, the skin with its implanted cartilage is transferred to the required site in the form of a pedicled flap whenever possible, the pedicle being severed later. This procedure admits of various modifications but it may be termed the standard method.

Cranial Defects.—Foreign bodies in the form of plates of various inert materials (silver, celluloid, etc.) have been used for the closure of cranial defects. The results were so uncertain and failure was so common that such procedures had to be abandoned. Dead and decalcified bone have been tried, but rapid absorption was the usual sequel. Pedicled flap operations of skin and bone are osteoplastic procedures proposed by Ollier, Durant, and Mueller-Koenig. Satisfactory results may be obtained with these methods in the repair of small cranial defects, but they are not applicable for the larger gaps. The final results of flap operations are so much more dependable than those of any free tissue transplantation that they should be employed whenever possible. Free bone grafts have been extensively used in the repair of large cranial defects. Many excellent results have been reported and various procedures have been advocated. Delangenière, in particular, described brilliant immediate results with the use of thin osteoperiosteal sheets, but thicker bone grafts are employed by most surgeons.

Grafts of cartilage are not as rigid as bone and can, therefore, be more easily molded. Cartilage is absorbed much more slowly than bone, allowing adequate time for replacement by a dense fibrous tissue that maintains the architecture of the graft. Remnants of cartilage have been found as long as two years after transplantation. In addition, the fibrous tissue that replaces cartilage makes a more resistant membrane than that replacing bone grafts. For these reasons I feel that it is more logical to use cartilage transplants for cranial defects than any of the other tissues that have been employed. In the hands of Villandre, Morestin, Mauclaire, Desgranges, and others, the transplantation of cartilage into cranial defects has yielded most satisfactory ultimate results.

It would lead too far afield to discuss the indications for cranioplasty for the repair of skull defects. The procedure is usually employed to replace large losses of substance due to injuries. It was used extensively during and after the World War for the repair of defects resulting from gunshot wounds of the head. Many manifestations have been ascribed to the skull defect as such, whereas they may have been referable to lesions in the brain itself. It is certain that the premature repair of cranial gaps may be a very dangerous procedure. The only proved value of cranioplasty is for the protection of the underlying brain and for cosmetic purposes.

Half-joint Transplantation.—This involves the transplantation of a bone with its articular surface. Successful results have been reported after reimplantation of a bone with its articular surface in the operative treatment of fracture dislocation. The only feature in which half-joint transplantation differs from bone transplantation is in the necessity for homoplastic material in most instances. As a rule, autoplasty is not possible except in operations on the hand, where phalanges of the foot may be used, or occasionally in replacing the lower articular surface of the radius, for which the upper end of the fibula with its joint surface has been employed. Except for transplantations of this type, homoplasty or heteroplasty have to be resorted to. Lexer, Kuettner, and others have obtained some brilliant results, using material from cadavers or from freshly amputated extremities. Reports of untoward results, such as fibrous encapsulation or absorption of the graft, have been made. Such results are not peculiar to joint grafts but may follow homologous transplants of any type, for reasons that are as yet obscure. As I have suggested in the discussion of other tissue transplantations, successful results may prove the rule if homografts are used from individuals in compatible blood groups.

Whole-joint Transplantation.—Up to the present time whole-joint transplantations have been limited to the knee-joint with the exception of a few cases of transplantation of the phalangeal joints. The indications for whole-joint transference are sharply limited. According to Lexer, the procedure is to be considered when a serious destruction of the joint apparatus from tuberculous suppuration or traumatism has resulted in a bony ankylosis or when large resections for tumors or traumatism have included the removal of the joint. The contra-indications must also be considered. In old people whole-joint grafts do not do well. Debility from chronic disease, such as pulmonary tuberculosis, is also a contra-indication. Most important is the condition of the articulomotor apparatus. It is manifestly useless to attempt joint transplantation when there is extensive muscular destruction or paralysis. It is also not to be tried in the presence of fistulae.

The complications that have been noted after joint transplantation are encapsulation, absorption, or an intra-articular fibrosis resulting in immobility. A late complication that Lexer has noted is the occurrence of manifestations similar to those in arthritis deformans. All ankylosed knee-joints are not equally suitable for transplantation. In grafting, after resection for tuberculous arthritis, infection may occur because of remaining tuberculous foci, or lost function may result from cicatrization of the tissues about the transplanted joint. Knee-joints that are the seat of transverse scars interfering with function are unsuitable for transplantation.

The only reported cases of autoplastic joint transplantation have consisted in the use of toe joints for finger joints; in one case, Goebell obtained a successful result with the transplantation of a phalangeal joint with its capsule. Despite a few successes in whole-joint transplantation, it is evident that the procedure is as yet in an experimental stage with a very unfavorable outlook for clinical application. In view of the complicated technic and the dangers inherent in failure, it is difficult at the present time to visualize conditions for which the procedure might be advocated.

Technic of Cartilage Transplantation.—The transplantation of cartilage *in the repair of cranial defects* usually involves the excision of cicatricial tissue occupying the operative field. The scar tissue is disfiguring and, in addition, it makes an unsatisfactory bed for any type of graft. After the cicatricial skin and subcutaneous tissues have been removed, the skin incision is appropriately enlarged fully to expose the cranial defect with its overlying scar tissue. In excising the latter, great care must, of course, be taken to avoid damage to the underlying brain. It is best to expose the dural surface at the periphery of the skull defect and to use this as a guide in the excision of the scar. When in doubt as to the situation of the brain surface, it is much wiser to leave some scar tissue behind and place the grafts over this. The margin of the skull defect should now be laid bare, projecting points being removed with rongeurs, and the dura gently stripped away from the under surface of the skull. This procedure permits the brain surface to fall away a sufficient distance to allow the placement of the grafts.

The cartilaginous grafts are taken from the sixth, seventh, and eighth costal cartilages, the head wound being packed in the interval. Removal of the grafts is facilitated by the use of a knife devised by Villandre. Most of the length and about half the thickness of each of the costal cartilages is usually required, and it is always better to remove larger sections than appear to be necessary for the repair of the defect. Some operators place the grafts between skull and dura, others into niches made in the diploë, but the simplest procedure is that advocated by Villandre. A catgut suture is applied across the gap in a zigzag manner, grasping the pericranium on each side. A trellis is thus made and the grafts are slipped in place beneath it. The grafts curl as they are cut, and are placed with their concavities facing the brain. The strips of cartilage should always overlap, the result being an exaggeration of the convex surface of the skull in the repaired area. The shaping of the cartilage pattern depends on the size and shape of the defect. The strips can be molded and bent to fit the various spaces accurately. If necessary the grafts may be doubled in order to fill in a deep defect. Drainage is not usually advocated but is surely a desirable procedure. Complete failure of the grafting operation may result from a hematoma. The drain can almost always be placed within the hair line and should not of course be in contact with the grafts. After its removal, nothing should be placed in the tract because of the possibility that infection may be introduced from the outside. In satisfactory cases, the end result is a resistant mass of tissue in which the bridge or bridges outlining the original graft are to be felt. Statistics of large series of cases would indicate success in the great majority of all instances in which cartilage grafts have been employed.

The general principles of technic in using cartilage grafts in cosmetic surgery have been discussed. The procedures will, of course, vary depending upon the object to be attained.

Half-joint Transplantation.—The technic to be employed is described in the section on bone transplantation. The method of fixation by wedging was noted as the most satisfactory means of holding the graft in place. The articular surface must, of course, be properly adapted to the opposing articular surface. Fixation within the joint not being possible, the articular end of the graft must be snugly held in place by attachment to the capsule of the joint.

Whole-joint Transplantation.—The site that is to receive the transplant is exposed by a generous incision and a large flap is turned back. The joint defect is then prepared by excision of scar tissue and the removal of unhealthy granulation tissue. The graft is removed under sterile precautions and stripped of all its attached musculature and tendons. The capsule of the joint is not included in the transplant. The graft is then placed in the desired position. Under most circumstances it is not necessary to use any method for holding it in place. It is undesirable to use foreign bodies, such as nails or plates, for fixation. The soft parts and skin are sutured over the graft. The new joint is then immobilized in plaster of Paris for a varying period of time, depending on the X-ray findings after transplantation.

Résumé of the Biology and Clinical Value.—Cartilage transplants undergo degeneration and replacement. The outstanding feature is the long interval preceding the stage of degeneration. Even after prolonged periods, the general shape and contour of the graft is still maintained. Epiphyseal cartilage undergoes degeneration and a fibrous replacement that may go on to ossification. It, therefore, always loses its specific function of producing growth in length of bones after transplantation, and is the least transplantable of all the components of bone.

In plastic surgery, cartilage has proved to be the most satisfactory of all grafts when rigid support is required. For the same reason, the cartilaginous graft is the most useful of all free transplants for the repair of skull defects, and the clinical reports of its uses have been very satisfactory. The transplantation of bone with its intact articular surface has a limited but favorable sphere of usefulness. Whole-joint transplantation is, as yet, in an experimental stage.

TEETH

Although the practice of replanting and transplanting teeth is to be classed among the oldest of tissue transplantations, the procedure is but little used to-day. As far back as 1593, Ambroise Paré described a case of replantation of teeth that he performed as follows:

Three teeth were loosened and almost torn out of their sockets. After treatment of the jaw the teeth were put back in their positions. . . . By this means I enabled him to masticate as formerly with the teeth. [He adds] I have also heard from a credible person who knew a noble lady that had a tooth extracted from her maid and replanted in the alveolus from which her own tooth had broken out. The tooth became as fast as if it had taken root and she could masticate as well with it as with her other teeth.

In the early part of the eighteenth century, the grafting of teeth was at its height, for servants of the nobility were willing to sacrifice their teeth for the purpose. Not a few cases of tuberculosis and syphilis were ascribed to the procedure, so that it became less and less frequently used. In John Hunter's book on teeth, published in 1755, there is a complete description of the operation of transplantation. He believed that a tooth must be implanted within twenty-four hours of extraction as that was considered by him to be the maximal period of viability. Hunter also performed experiments with the transplantation of a tooth in a cock's comb and was able to demonstrate vessels in the pulp some months later. From this observation, he inferred that a regeneration of the severed pulp took place.

The more recent literature on the subject is scant and the publications, with few exceptions, consist mainly of isolated clinical descriptions of cases in which replantation or transplantation of teeth are attempted.

The replantation of teeth was first used in modern times (Richter, Lomnitz, Coleman) in the treatment of chronic disease of the peridental membrane. The tooth was extracted and, after excision of the diseased part, was then replanted. Magitot, in 1879, reported a series of one hundred and twelve cases of replantations or transplantation of teeth, some of which were followed as long as two and one-half years after operation. He stated that inflammatory reactions were seen in twenty-five of the cases, but that only eight were complete failures. A few years later Morrison reported a large series of similar cases and described satisfactory results with the procedure, but did not mention the length of time that his cases were observed.

William Younger, in 1886, was apparently the first to be interested in the phenomena of repair following the transplantation of teeth. From his observations he concluded that a replanted tooth becomes fixed in place because of the regenerative properties of the peridental membrane. He believed that the membrane maintained its viability for a short time after the extraction of a tooth. This led him to implant teeth in a cock's comb in order to have them on hand with "live periosteum" when needed for transplantation. In one instance, he transplanted a tooth extracted some months previously; it became "as firmly attached as a tooth replanted immediately after extraction."

The first to experiment on animals and endeavor to determine the fate of the graft by microscopic studies was Leon Fredel, in 1887. He concluded that periosteum was essential for successful transplantation because it prevented absorption of the tooth, and that consolidation and reunion were due to renewed viability of the periosteum. This work was corroborated by the experimental studies of Scheff, who arrived at similar conclusions in regard to the importance of the periosteum. Experiments were conducted at a later period by Mendell-Joseph to determine the relative value of the various types of grafts. His attempts to transplant teeth stripped of their membrane resulted in failure. In each case the tooth was extruded soon after implantation. He succeeded, however, in transplanting a dead tooth; the implant became fixed to the alveolus by osseous tissue. This was the first demonstration of bony fixation of a tooth graft. Mendell-Joseph concluded that a dead tooth was better material for transplantation than a viable one deprived of membrane.

An analysis of the clinical reports that subsequently appeared shows that the root eventually becomes absorbed and that the tooth is extruded in the great majority of instances. The period of retention of the graft varies greatly. The tooth is usually extruded within the first three years, but has been occasionally retained for as long a period as five years. There is a report of one case in which a replanted tooth remained in place for seventeen years.

The work of Wilkinson seems to comprise the best experimental investigation of the subject. He describes an early and irregular absorption of the roots. In some places the cementum remains intact while in others it is rapidly absorbed. Large multinuclear cells are present next to the partially absorbed cementum and dentin. If the membrane is present, it dies shortly after transplantation. Absorption of the graft does not appear to occur as rapidly when the membrane is intact. It seems to us that the peridental membrane of the tooth plays a rôle similar to that of the periosteum of bone, its presence tending to retard absorption and inviting a more rapid union between the transplant with the host (see section on Bone). The cementum and dentin, becoming absorbed, are not regenerated but are replaced by calcified connective tissue. The attachment between the alveolus and the root of the grafted tooth is usually by fibrous tissue. The description Wilkinson gives is really that of the formation of a vascular granulation tissue into which fibroblasts grow, with scar tissue as the end result. In some instances, calcification takes place in the newly formed fibrous tissue, resulting, finally, in a bony union between the alveolus and cementum of the root. Some sections are characterized by the presence of long connective tissue fibers simulating the normal peridental membrane. The histologic picture shows a death and replacement of the transplant, a gradual process usually terminating in an unsatisfactory result.

Technic.—The technic as described by Wilkinson is as follows: an impression of the teeth is taken in wax, from which a splint is made to retain the teeth after implantation. The best procedure is the replantation of extracted teeth. If this cannot be done, freshly extracted teeth from other sources are used. After drilling through the crown of the transplant, the pulp is removed and the empty pulp chambers filled with ox para, which is sealed in with cement. The graft is placed in normal saline solution before replantation. The gums and adjacent teeth are then painted with iodin. If the tooth cannot be fitted into the original bed, the socket is enlarged with a burr before its implantation. The metal fixation splint is then applied. This is usually removed in ten days, by which time the graft has become firmly attached.

Clinical Value.—There have been a sufficient number of successes reported to warrant some clinical application of the transplantation of teeth. Since the perfection of prosthetic appliances, the tendency in recent years has been to abandon the procedure. It would appear that the gratifying results that may be obtained by successful transplantation or replantation of teeth should lead to further clinical investigation of the subject.

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CHAPTER VII

THE TRANSPLANTATION OF BLOOD-VESSELS

The transplantation of blood-vessels is one of the modern developments of tissue grafting. It was made possible by the introduction by Carrel and Guthrie of an adequate method of blood-vessel suture. A remarkable development of the subject has resulted, and blood-vessel grafting now rests on a solid clinical foundation.

The inception of the idea of blood-vessel transplantation may be said to date from 1896, when Jaboulay and Brian attempted experimental transplantation for arterial defects. In 1903, Hoepfner made a careful investigation of the subject and, in a series of successful experiments, demonstrated that the circulation might continue, for a time at least, through homografted as well as autografted arterial segments. He suggested the use of arteries from recently deceased individuals for the repair of arterial defects in the human being. Although unsuccessful in his efforts at the repair of defects by vein implantation, because of technical difficulties, Hoepfner proposed their use as a solution of the problem of obtaining autografts in clinical surgery.

With the evolution of better technical procedures, many experiments were performed in the succeeding years, ultimately placing the method on a sufficiently sound basis for its introduction into human surgery. In analyzing the conclusions that have been arrived at in blood-vessel transplantation, the difference between the functional and the anatomic (histologic) result of blood-vessel grafting must be clearly appreciated. This aspect of the subject requires some discussion if an attempt to clarify the rather confused present-day viewpoint is to be made.

From the studies of Carrel and Guthrie, of Stich, Makkas, and Dowman, and of others, the conclusion was reached that arterial autografts persisted as such, remaining viable for one or two years and even longer after transplantation. It appeared evident that permanent function of the new-formed channel could be anticipated under such circumstances, and that expanding and contracting muscular walls would aid in the propulsion of the blood stream. Sufficient histologic data to verify this assumption was not forthcoming; in its absence, permanent viability of transplanted vascular segments remains unproved. On the other hand, the work of Borst and Enderlen (often quoted as proving persisting viability) and of others indicates clearly that there is no histologic support for this view. In the studies made by these investigators, the supposedly original transplants were recognized as being fibrous replacing tissue so closely simulating the structure of the original grafts that a false interpretation might easily be made.

An examination of the work that has been done teaches us that the macroscopic appearance of a transplanted artery, so often offered as the sole criterion of its viability, is absolutely no proof of the living state of the graft. Concerning the *histologic changes* that occur in arterial autografts, the following may be said to summarize the phenomena: within a very short time after implantation (a day or less), edema of the endothelial cells exists, and minute thrombi are to be found at the lines of anastomosis. There is an invasion of the adventitia by wandering cells, and fibroblasts extend into this layer from the surrounding tissues of

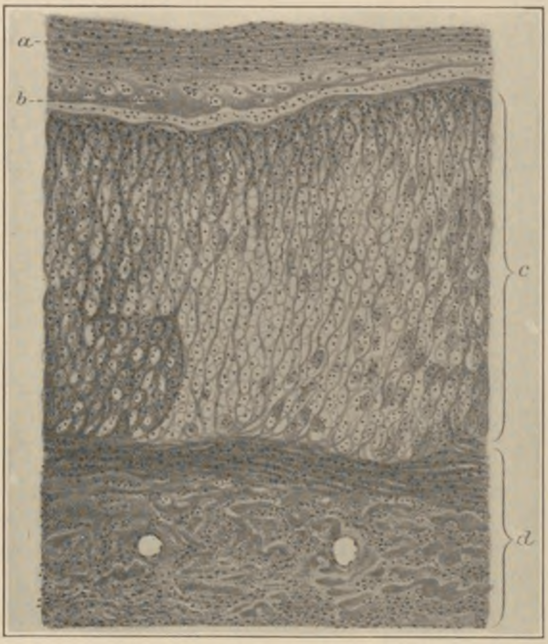

FIG. 95.—HOMOTRANSPLANTATION OF CAROTID IN A GOAT AFTER TWENTY-NINE DAYS.

A, intima extending from the adjacent arterial wall across the graft. *b*, hyaline degeneration and leukocytic infiltration of the intima. *c*, beginning degeneration of the media. *d*, adventitia occupied by hyalinized connective tissue and leukocytes and undergoing replacement (Borst and Enderlen).

the host. The adventitia becomes a richly cellular layer with many new-formed capillaries derived from the adjacent tissue. Only limited evidences of regeneration are to be seen in the media, slow replacement of the elastica and muscle fibers by fibrous tissue being the typical picture. The intima becomes a fibrocellular layer in which the thrombi that have formed ultimately disappear. A layer of "endothelium" covers the free surface of the graft, but whether this represents regeneration from the endothelium of the graft, as is usually maintained, or connective tissue cells at the surface that have undergone metaplasia remains to be proved. The possibility of extension from the adjacent endothelium of the host cannot be overlooked. Regeneration of elastic fibers, proceeding presumably from the adjacent arterial wall, is seen at an early stage, especially in the subendothelial zone. In short, the phenomena are those of gradual fibrous replacement of the autograft, in which a differentiation of the individual layers of the transplant becomes less and less marked as time goes on.

The histologic examination of successful homografts of arteries reveals a picture closely analogous to that found in autografts. The same slow and gradual replacement of the progressively disintegrating transplant is usually seen, together with an endothelioid covering of the free surface. We recently compared the microscopic drawings and photographs of homografts and autografts of specimens that had been removed many months after implantation and were unable to detect any appreciable differences between them.

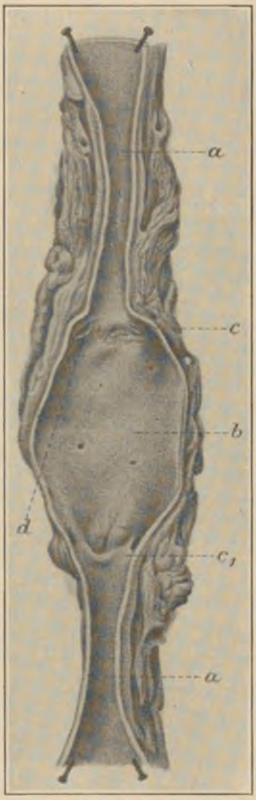

FIG. 96.—AUTOTRANSPLANTATION OF THE JUGULAR VEIN INTO THE CAROTID ARTERY IN A DOG AFTER NINETEEN DAYS.

a, *a*, carotid. *b*, hypertrophy of the implanted segment of vein. *c*, *c*, site of suture. *d*, silk thread projecting into the lumen (Borst and Enderlen).

In heteroplasty of arteries, on the other hand, rapid disintegration of the transplant occurs in the majority of instances. There have been some experiments in which replacement has taken place almost as slowly as in isotransplantations and autotransplantations, but they were exceptional. Massive thrombosis at an early stage is the rule, yet some type of channel through a tube of fibrous tissue appears and persists in a surprisingly large proportion of the experiments with heterografts.

The use of dead, preserved, arteries for implantation into defects was introduced by Carrel and Guthrie. They reported successful results, as evidenced by the persistence of tubes of fibrous tissue, after ice-box preservation of the grafts in Locke's solution. Only a small percentage of satisfactory results was obtained by others, necrosis and suppuration or aseptic thrombosis occurring in the remainder. Implantation of arteries preserved in formalin and in alcohol has been followed by similar results.

Surveying the *clinical applicability of arterial grafts*, it is clear from what has been said that fresh homografts would serve almost, if not quite, as well as autografts, but that the use of heterografts and preserved arteries is too uncertain and unsafe in human surgery. It has not been proved that thrombosis occurs more frequently after homografting than after autografting with experimental material, yet one cannot avoid the impression that it will often occur clinically. In this connection, the reported experimental results cannot be a guide as to what may happen in the human being, for the blood of experimental animals does not present the clean-cut group characteristics that are found in man (see Chapter I). It is conservative to say that thrombosis will occur in homografts in the human being whenever blood incompatibility exists. With this in mind, and in view of the difficulties to be encountered in obtaining normal fresh arterial segments under aseptic conditions, homotransplantation of arteries in clinical surgery is not warranted. Despite the great amount of experimental work that has been done on arterial transplantation, one is able to visualize only rare instances in which the results may be applied to the human being. For, autografting of arteries being the only safe method, the required material is not obtainable. The problem of vessel transplantation comes up only in lesions of the larger arteries, and arteries of approximately

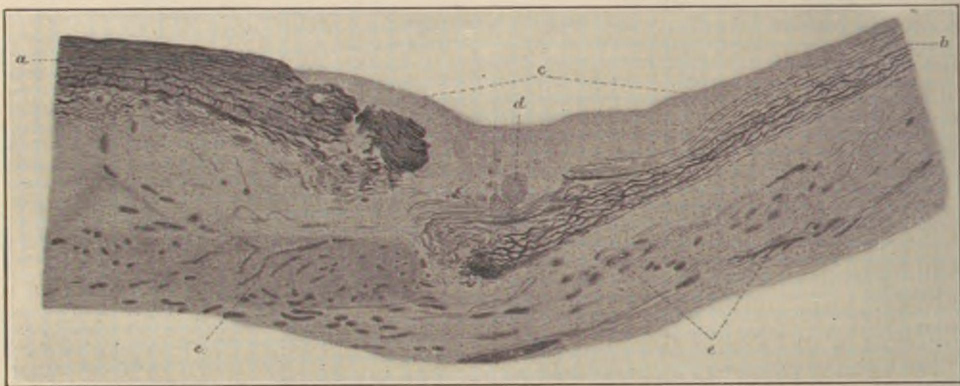

FIG. 97.—SAME AS IN FIG. 96, SHOWING THE JUNCTION BETWEEN THE TRANSPLANT (ON THE RIGHT) AND THE ARTERY (ON THE LEFT).

a, carotid. *b*, vein. *c*, newly formed intima. *d*, silk suture. *e*, *e*, thickened adventitia with many blood-vessels (Borst and Enderlen).

the same caliber would, of course, be necessary to supply the missing segments.

Turning to the question of *the transplantation of veins* into arterial defects, it has been stated that the method was originated by Hoepfner. Carrel and Guthrie, however, were the first to employ the procedure successfully. Since that time (1905), grafts of veins have been successfully transplanted, not only experimentally, but also in a number of clinical cases.

The histologic changes that occur in the graft have a direct bearing on the practical application of the method in clinical surgery. Aneurysmal dilatation from the pressure of the blood stream was at first anticipated but this does not occur as a rule. On the contrary, a macroscopic increase in density and a thickening of the wall of the vein takes place as early as a few weeks after transplantation. The change is due to an increase in connective tissue in all three layers and the addition of an enveloping fibrous tissue derived from the host. Hypertrophy of and increase in the muscle fibers of the media is said to occur and has usually been interpreted as a functional adaptation of the vein to arterial pressure.

We cannot accept, as proved, regeneration of the musculature, and believe that the increase in thickness in and about the transplant is a fibrous tissue infiltration induced by the arterial pressure. Analogous changes are seen in transplants of other tissues subjected to tension, as in fascial grafts implanted into tendon defects. Indeed, it has been shown that replacement by a thick fibrous tissue lined with endothelioid cells on the free surface occurs when fascia is grafted into arterial defects (see Chapter IV). An increase in thickness is not seen when segments of vein are transplanted into defects of veins and it may be assumed that it would not occur if the blood-pressure were reduced after transplantation of veins into arteries. Connective tissue infiltration is most marked in the parts of the graft adjacent to the ends of the artery, but exists throughout the transplant. The

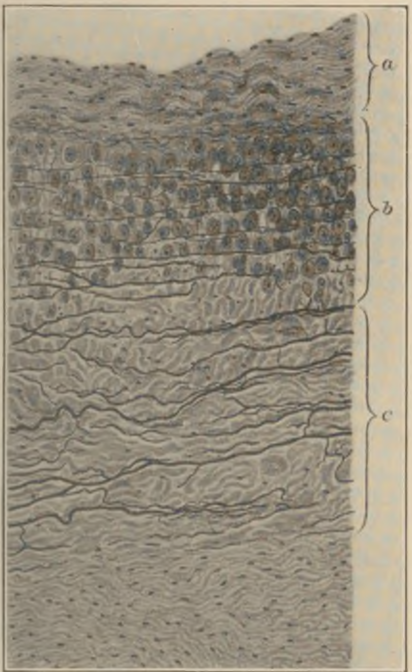

FIG. 98.—SAME AS IN FIG. 96, SECTION OF THE HYPERTROPHIED VEIN NEAR THE ANASTOMOSIS.

a, intima. *b*, media. *c*, adventitia (Borst and Enderlen).

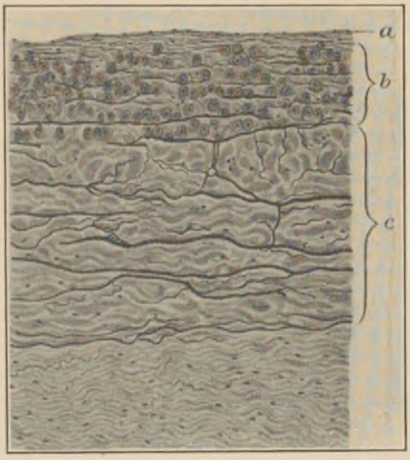

FIG. 99.—SAME AS IN FIG. 96, SECTION THROUGH THE MIDDLE OF THE TRANSPLANTED VEIN.

Lettering as in previous figure (Borst and Enderlen).

ultimate result is a resistant tube of fibrous tissue lined by a layer of endothelioid cells continuous with the arterial endothelium, a channel that is capable of withstanding the intra-arterial pressure indefinitely.

Some writers maintain that the results of homotransplantation of veins are different from those of autotransplantation, being characterized by early degeneration and replacement by the host's tissues. From what has been said, it is clear that we consider such changes to be typical of autografts as well, and are unable to perceive any great difference in the histology in the two cases. An argument advanced in favor of autografting is that early degeneration and thrombosis occur more frequently after homotransplantation. An examination of the literature indicates that the number of experiments is all too few to establish the truth of this assertion. It may be said *a priori* that thrombosis will be encountered whenever the recipient and donor are of incompatible blood groups. The subject of heterotransplantation of veins may be dismissed with the statement that failure is the usual sequel.

After the experimental demonstration of the efficacy of autotransplantation and homotransplantation of veins for arterial defects was made, the advantages of vein over artery grafts were soon appreciated from a clinical point of view. The practical difficulties of obtaining homografts were recognized and it was equally clear that autografts of veins might almost invariably be detached without any serious interference with the circulation. A segment of the saphenous vein will serve for the replacement of defects of the largest arteries, with the exception of the aorta, or the internal jugular vein may be utilized, if it lies near the operative field. Clinical experiences have demonstrated that the transplanted vein successfully withstands the intra-arterial pressure after operation, and that conversion into a permanently resistant tube of fibrous tissue occurs as it does in experimental cases. Autotransplantation of veins may, therefore, be said to be the best method for the replacement of arterial defects.

Technic.—Whenever blood-vessels are used as transplants for arterial defects, the technic involves detachment and preparation of the graft and its implantation by two end-to-end anastomoses. It is evident that all the refinements in technic that have been discussed as essential in tissue transplantation (see Chapter I) must be employed to a superlative degree in blood-vessel grafting. The latter is in a class by itself, for the reason that a single error in technic may readily vitiate the entire result. The special problem is the elimination of thrombosis in the lumen. The methods of anastomosis have been devised with this end in view, but perfect end-to-end suturing will not eliminate coagulation and subsequent thrombosis if other errors in technic have been made. Transplantation of other tissues does not require special training, but it is essential for surgeons to become thoroughly familiar with vessel transplantation in the laboratory, if satisfactory clinical results are to be obtained.

Minimal trauma in the removal of the graft is imperative. Grafts should not be detached until the indication for their need is evident, and, therefore, the various elaborate methods that have been described for keeping the transplant before transference are not of great importance. Another advantage of direct transference is that the exact length of the graft may be estimated in advance and unnecessary trimming, always time consuming and traumatizing, is thereby avoided. In determining the length of the graft, the shortest section that will adequately replace the defect should be chosen. In general, one may say that the longer the transplant, the less the chances for a perfect result, although sections of veins 14 to 16 cm. long have been successfully implanted. The graft should not be handled by forceps or other instruments except when necessary for the passage of fixation sutures. In choosing the portion of a vessel for grafting, sections bearing lateral branches should not be used if possible to avoid them; when branches are unavoidable they are ligated close to the main trunk before detaching the transplant. Liquid paraffin or vaselin is usually employed throughout the operation; either one or the other is applied to the suture material, to the mouths of the vessels, and is used to flush the interior of the transplant. For the last mentioned purpose, one half of one per cent (0.5) solution of sodium citrate should prove of greater value because of its usefulness in inhibiting coagulation. The interior of the graft is flushed with the citrate solution until entirely free from blood. In this step, as well as in the remainder of the operation, rough handling of the delicate intima is almost certain to be followed by thrombosis and failure. This statement applies as well, of course, to rough handling of the intima of the artery receiving the graft. If a vein is used for implantation, as is usually the case, the poles of the graft must be reversed so that the blood stream will not meet the opposition of the valves. End-to-end anastomosis between the graft and the divided ends of the artery is the simplest and best method of implantation.

Specially made, flexible needles of very fine diameter and delicate split strands of silk prepared for the purpose, by immersion in liquid paraffin or vaselin, are necessary for vascular anastomoses. Squares of chiffon, either black or white, depending on whether white or black sutures are used, placed under the vessels and about the field, aid in seeing the suture material, the exact points for passing sutures, etc. The graft is kept moist while the anastomoses are made. For this purpose and for flushing the vessel ends while the sutures are being passed, we advocate the use of sodium citrate rather than normal salt solution. A sodium citrate solution might be employed with advantage throughout the operation in the form of a gentle irrigation of the field.

End-to-end anastomosis is performed by passing two or three traction sutures and then making a continuous suture between these two or three points of approximation. Instruments have been devised to hold apart the ends of the traction sutures in order to facilitate the passing of the continuous stitch. They have the advantage of reducing the number of hands in the field besides holding the vessel ends wide open. Two traction sutures suffice for some surgeons, but three are better, especially in aiding in the exposure of the posterior portion of the anastomosis. Whatever form of traction and continuous sutures are employed, the essential step in avoiding thrombosis is the eversion of the intima of the artery and of the graft along the line of the anastomosis, so that intima-to-intima approximation is attained throughout. To accomplish accurate apposition of the intima, the adventitia at the cut ends of the vessels is drawn down with forceps and the excess portion ablated. The customary suture is the usual continuous stitch. A continuous mattress suture, with or without the addition of the former, may be employed when unusual tension is anticipated. Occasionally the diameter of the transplanted vessel (vein) does not coincide with that of the end of the artery. Under such circumstances the sutures may be passed with a broader bite on one side than on the other, in order to obtain an exact fit. Another expedient that may be employed, when the diameter of the vein is smaller than that of the artery, is to cut the end of the vein obliquely. After the anastomoses are completed, the distal serrefine clamp on the artery is first removed and then the proximal clamp is slowly opened to permit the blood stream to flow through. Pressure over the anastomoses by moist sponges will usually control any oozing that may occur through the stitch holes, but reënforcing sutures may be necessary.

In one case in which thrombosis occurred at the site of anastomosis during operation, the surgeon (Unger) incised the artery, removed the clot, and restitution of the circulation followed. Lexer believes that such a procedure would not usually suffice and advocates flushing with liquid paraffin, in addition to removal of the clot, until no further thrombosis occurs. The use of sodium citrate solution, introduced through a very small calibered needle, might prove more efficacious for this purpose, the solution being kept in contact with the involved section by re-applying the serrefines to the artery.

Closure of the soft parts over the transplant is carefully carried out so that compression of the graft does not occur, but the tissues should fit snugly to avoid leaving any dead spaces. Broad contact between normal nonfibrous tissue of the bed and the walls of the transplant is most desirable. The reparative phenomena from the host that must ensue if a successful result is to be obtained are thereby invited. Tight compression dressings are not to be used.

Whole vessel transplantation has been discussed as the typical method for the treatment of arterial defects. Other procedures involving the use of foreign bodies have been advocated but are not of proved value.

The operative treatment of partial (lateral or parietal) defects of arteries has been conducted in another manner. Carrel introduced the method of patching such defects by using sections of artery or vein, or by implanting free grafts of peritoneum with muscle. We have indicated elsewhere (see Chapters III and IV) our belief that the use of identical or similar tissue for the purpose was based on the unproved assumption that the grafts retained their original structure and functioned as such. Successful experiments with fascial grafts for arterial defects are described elsewhere. We are not acquainted with any satisfactory grafting technic for lateral defects of arteries in the human being other than the one we use, and, inasmuch as two successful clinical results were obtained with fascial transplants, this may be considered the method of choice until the more complicated procedures that have been advocated are shown to offer as good or better results.

Indications.—Whenever ligation of an artery will lead to necrosis of a limb, cerebral degeneration, etc., and when alternative procedures are not applicable, blood-vessel grafting may be considered. However, if simple ligation is not dangerous to life or limb, transplantation should be avoided. When a vascular lesion has existed for some time, the collateral circulation may provide sufficient blood supply to the distal parts. The distal stump of the artery must always be examined before blood-vessel transplantation is considered, to determine whether blood flows freely from it when the proximal stump is clamped (Henle). The flow of blood in jets from the distal end is sufficient proof of an adequate collateral circulation.

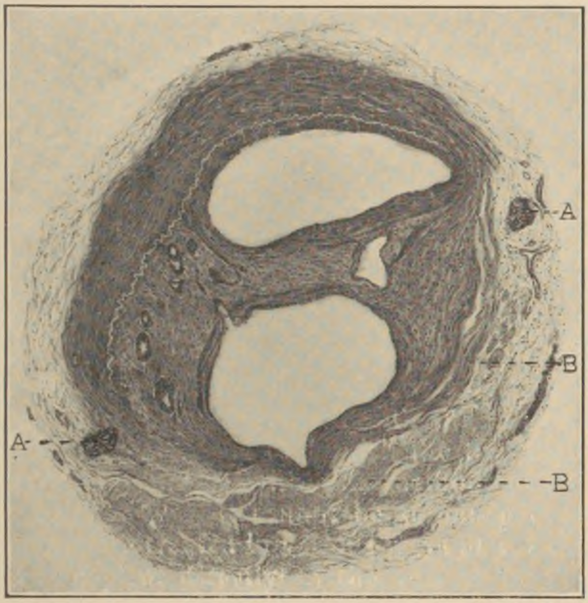

FIG. 100.—THROMBOSIS AND CANULIZATION FOLLOWING A FASCIAL GRAFT INTO A DEFECT OF THE FEMORAL ARTERY.

Picture drawn six months after operation. The elastica as well as the silk sutures at *A*, *A*, indicate the termination of the arterial wall. The transplant, *B*, *B*, has undergone degeneration and fibrous tissue replacement. The well-developed walls of the newly formed vascular channels are clearly shown.

If ligation of an artery cannot be accomplished safely, the alternative need not necessarily be blood-vessel transplantation even when a considerable hiatus exists between the ends of the arteries. The ends may be mobilized sufficiently for end-to-end suture, the approximation being aided by flexion or other postures in arterial lesions near joints or in the neck. Lateral arterial defects, even of large size, should not be treated by resection with attempted end-to-end suture or blood-vessel transplantation. I have shown that they may be adequately dealt with by the simpler and safer method of fascial grafting. However, blood-vessel grafting is preferable to end-to-end suture under tension, or to suture made difficult by extreme flexion of joints. A typical indication for blood-vessel grafting exists when a long section of an artery must be sacrificed in the removal of a tumor and simple ligation would result in gangrene.

A discussion of other operative procedures that have been employed in the treatment of true or false aneurysms would lead too far afield. Attention may, however, properly be directed to the brilliant results that have been obtained by aneurysmorrhaphy as originated by Matas, a method that is especially serviceable in aneurysms of syphilitic origin.

Contra-indications.—Blood-vessel transplantation may be practiced safely only in a well-nourished field. When the latter is occupied by extensive cicatricial tissue, conditions are unfavorable for the reparative phenomena about the graft, so essential to success. For a similar reason the procedure should not be attempted when the operative area is the seat of an extensive hematoma infiltrating the tissue layers about the vascular lesion. The presence of infection is an absolute contra-indication to blood-vessel grafting. The danger always inherent in any blood-vessel transplantation should not be glossed over by using the few brilliant results that have been obtained as a text. The operation is a prolonged one. Thrombosis at the site of operation may not simply invalidate the result; thrombi may be swept into the blood stream with unfortunate or even fatal sequelae. Failure after transplantation may be followed by serious arterial hemorrhage. If these ever-present possibilities are borne in mind, blood-vessel transplantation will be practiced only when it is the sole remedial measure that is practicable for the situation.

Results.—Of the seventy or more cases of blood-vessel transplantation that have been reported, apparent success has occurred in more than half, but persisting patency of the transplant has been proved in only a very small number. By apparent success is meant the avoidance of gangrene or the absence of any evidences of an impoverished circulation without the proof of blood-flow through the transplant. The functional result may, therefore, be considered satisfactory in most of these cases. It must be inferred, however, that slow occlusion of the graft occurred in many cases and that the good results in these were due to a gradually developing collateral circulation.

Transplantation of Veins for Defects of the Urethra.—The use of vessel segments for the replacement of destroyed or absent portions of the urethra was introduced in 1908. Since that time a number of successful reports have been made, particularly in the treatment of hypospadia and in the replacement of the urethra after its resection for stricture, etc. Before the clinical work was done, some experiments had been undertaken in the reconstruction of the common bile duct, urethra, ureter, and vas deferens by vessel segments. On the whole the results were most unsatisfactory, early degeneration of the transplant and leakage being the usual sequel.

Nevertheless, it must be borne in mind that the chances for repair about a vessel transplant are better in the human being than in animals, especially in the replacement of urethral defects. Several stage operations may be practiced and the urinary stream can readily be deflected by suprapubic cystotomy or perineal drainage. Strictures that may subsequently appear are adequately dealt with by dilatation. It is for this reason that better results have been obtained in human than in experimental surgery. A most satisfactory clinical use that has been made of a blood-vessel transplant is in the replacement of defects of the urethra. Almost all the reported cases were successful, the resulting new-formed channel remaining patent. Urinary fistulae after operation were, indeed, common, but closed after varying periods. Dilatation of the channel by bougies or sounds may be necessary to maintain patency in some cases. In one instance, an opportunity was afforded to make a histologic examination five weeks after vein implantation, and it was found that the original structure of the graft had entirely disappeared. The caliber was, however, maintained throughout, and the free surface of the graft presented flat connective tissue cells, but no epithelial lining.

Indications.—Of all the tissue grafts employed for the replacement of urethral defects, the transplantation of veins has best served the purpose. The indications for its application are: first, those unusual instances of urethral defects in which mobilization of the urethra does not succeed in approximating the ends; and secondly, some of the difficult cases of hypospadia in which the usual operative procedures do not suffice.

Technic.—The implantation of a segment of vein must often be preceded by a suprapubic cystotomy, and the treatment of an existing urethritis or cystitis, etc. In hypospadia, the new channel is first made by the introduction of a trocar. According to Lexer, the trocar should be left in place for one or more days in order to eliminate the oozing that might occur if the graft were implanted at once. In all the successful cases, however, the segment of vein has been grafted in a single operation. An appropriate length of the saphenous vein is excised, the poles reversed, and the transplant is drawn through the channel. End-to-end suture to the urethral stump is then practiced, or, according to Pignatti's technic, the end of the urethra is invaginated into the vein. The other end of the vein is either sutured to the lips of the new urethral opening or is left to project beyond it. Judging by the results we have seen in appendicostomy, in which a part of the appendix is left out of the wound, the excess portion sloughing away, a similar projection of the vein transplant should make for a more satisfactory urethral opening than the suture of the end of the vein to the skin. Early dilatation with bougies has usually been employed after vein implantation, but the trauma inflicted to the graft must lead only to undesirable sequelae. We would advocate gentle distention of the vein transplant and urethra with solutions introduced from time to time as a preferable means of aiding in the maintenance of patency.

Before transplanting vein segments for defects of the urethra following its resection for stricture, all inflammatory foci must be eliminated. The method of implantation of the graft consists in suturing one end to the upper stump of the urethra and drawing the other end through the distal portion of the urethra and out through the meatus. This technic is simpler and appears safer than that involving the suture of the vein to the distal as well as the proximal ends of the resected urethra.

A defect of the floor of the urethra was adequately cared for, in a case described in Chapter IV, by fascial grafting; and a complete defect of the urethra was replaced successfully by a fascial tube according to a recent report made by Brenner. A fascial tube will probably not prove as serviceable as a vein graft for the repair of complete defects, but subtotal lesions can probably be better treated by a fascial transplant than by any other tissue graft.

The Transplantation of Vessels for Nerve Defects.—The various tissues that have been used in the bridging of nerve defects include arteries and veins, autogenously or heterogenously obtained. In the experiments very little nerve sprouting occurred in the empty vascular tubes, according to the reports of most observers. Edinger, therefore, suggested the use of hardened calves' arteries filled with agar.

A detailed description of the results that have been obtained is unnecessary. The evidence has not been sufficiently encouraging to indicate that the method is of great clinical value (see Chapter V). Other procedures, the transplantation of nerves in particular, appear to offer better results.

The Clinical Value of Blood-vessel Transplantation.—This is firmly established in two conditions: the replacement of long defects of the larger arteries, and the replacement of urethral defects. The method is serviceable and readily applicable for the latter purpose. Grave dangers are inherent in blood-vessel grafting for arterial defects. Any alternative methods that may be more safely employed should, therefore, have first choice. An autograft of a vein is the best transplant for an arterial defect, a thick-walled, patent, and resistant channel being the usual end result.

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CHAPTER VIII

THE TRANSPLANTATION OF ORGANS

Only an exhaustive survey of the numerous efforts that have been made to transplant the various organs will convey some idea of the enormous amount of work that has been done in this field. The complete history may be said to be one of the formulation of theories from time to time, in the train of each of which many investigations have been conducted. A first wave of enthusiasm has been succeeded by a period in which an accumulation of sober facts has cooled the earlier ardor. Biedl, Knauer, and others have described the evolution of the transplantation of organs and have given in detail the work of the host of investigators. A more brief consideration of the state of our knowledge of the subject at the present time will here suffice. I have dealt in previous chapters with tissue transplantation in relation to clinical value; to present in a like manner a subject that has as yet such limited applicability in surgery would create a false impression of its present significance.

The general principles of tissue transplantation that have been laid down (see Chapter I) hold with equal force in organ transplantation. The discrepancy is found in the fact that the object to be achieved is attainable practically with tissues but not with organs, at least with our present knowledge and methods. There are two fundamental reasons for this. Prolonged or permanent viability is not ordinarily essential for tissue grafting, whereas it is the *sine qua non* for organ transplants. Autotransplantation, offering the best outlook for success, can usually be practiced with tissues, only very rarely with organs.

Homotransplantation and, to a much less degree, heterotransplantation are the only clinical possibilities with organs. It was thought that, with the evolution of a satisfactory technic of blood-vessel suture, homotransplantation of organs might be made practicable. Aside from the difficulties, amounting to actual impossibility in most cases, of vascular anastomoses for the transference of smaller organs, the outcome has, unfortunately, fallen far short of what had been hoped for. In fact, the grafting of thin sections of organs, rather than of whole organs with or without blood-vessel suture, has, as a rule, offered a better measure of success.

The possibilities of transplantation of organs in the future cannot, as yet, be safely predicted, for a firm foundation on which further work may be built has not been laid. At the present time, I see but one tangible factor that has not been taken into account—tissue compatibility. Although the cause of this phenomenon is unknown, its existence and its high development in the human species is recognized. In the consideration of the transplantation of the various tissues, we have repeatedly emphasized our belief that blood compatibility should prove a basis for satisfactory results in homotransplantation. I believe that there can be no outlook for success in homotransplantation of organs unless the importance of this factor is recognized and taken into account. For if it holds true for homotransplantation of tissues, may not tissue compatibility prove to be the key to a solution of the problem of successful homotransplantation of organs?

The Thyroid Gland.—Not only the transplantation of the thyroid gland, but also the whole subject of transplantation of organs dates from 1854, when Schiff began his studies of the manifestations following removal of the thyroid gland. At a later period he experimented with transplantation of thyroid glands and discovered that the striking symptoms following total thyroidectomy did not appear at the usual time when

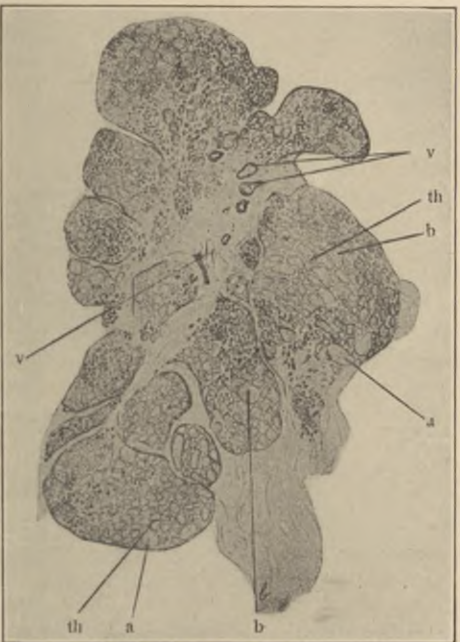


FIG. 101.—SECTION OF A PORTION OF AN AUTOTRANSPLANT OF THE THYROID THREE YEARS AFTER OPERATION. (Cristiani and Kummer.)
Th, thyroid tissue, the size of the alveoli remaining within normal limits. *v.v*, blood-vessels.

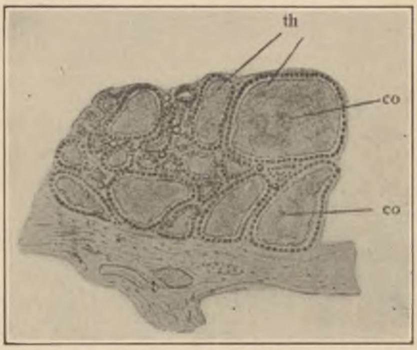


FIG. 102.—A PORTION OF THE PREVIOUS SECTION UNDER THE HIGH POWER. (Cristiani and Kummer.)
This shows *co*, colloid substance and *th*, alveoli with cubical epithelium.

the gland was implanted into the abdominal cavity. It was not until 1894 that partial success in autotransplantation of the thyroid was attained (von Eiselsberg). The gland was totally extirpated and transplanted into the abdominal wall. Upon microscopic examination, three months later, it was found that the peripheral portions of the graft stained well and the acini were occupied by colloid, but degeneration had taken place in the central part of the transplant. The results of investigators in the next period are of little value to-day, for tetany, only recognized at a later date as referable to removal of the parathyroid glands, was accepted as the cardinal sign of thyroid deficiency. Cristiani was the first to clearly demonstrate that autografts of thyroid gland might heal in place and function as such, particularly when the organism required thyroid substance. He also showed that successful homotransplantation was possible in some of the lower animals.

Shortly after the work of Cristiani and corroborative observations of others appeared, surgeons began the heterotransplantation of thyroid (using sheep's glands) to man for the treatment of myxedema. After a first stage of enthusiasm, it was gradually realized that the results were only transient and that improvement ceased as soon as the transplant was absorbed. About this time, Kocher began the homotransplantation of the thyroid gland for the treatment of cretinism and myxedema, using the spleen, bone marrow, and subcutaneous tissues as beds for the grafts. Only temporary improvement followed in the severe cases, but lesser grades of thyroid deficiency were greatly improved over long periods of time. In the absence of reports of microscopic studies of the grafts, it is impossible to determine if the excellent results that followed in some cases were dependent upon viability of the homograft or upon increased activity of the individual's own thyroid gland.

In contrast to the doubtful results of homotransplantation, a remarkable case reported by Cristiani proves with finality that the thyroid gland may be successfully autografted. An almost total thyroidectomy was performed for hyperplastic disease. Two small fragments that were apparently healthy were implanted under the skin in the deltoid region. Several weeks after operation they could be felt as small nodules. They gradually increased in size, as evidenced by elevation of the skin. The patient remained free from any signs of thyroid deficiency. A portion of one of the transplants was removed three years after operation. Upon microscopic examination, all the evidences of functioning thyroid tissue were found, without signs of degeneration. A similar microscopic picture was seen in a section removed from one of the transplants *twelve years* after operation.

The very limited possibilities inherent in thyroid transplantation in surgery are evident. Autotransplantation may be successful but a clinical indication for such a procedure rarely, if ever, arises. The only hope rests in homoplasty, and transplantation of fragments of glands as well as whole glands by blood-vessel suture has not as yet given results to warrant any clinical application at the present time.

The Ovary.—The first experimental studies, performed by Knauer, demonstrated transient viability of autografts of the ovary. Although the microscopic examination revealed graafian follicles, there were also evidences of disintegration and replacement of the transplants. In later work (1897), Knauer continued his experiments in autotransplantation, attaching the ovaries to the parietal peritoneum and to prepared pockets in the abdominal wall. A small number of the experiments were truly successful, pregnancy occurring after the transplantation of both ovaries. On the other hand, failure attended his efforts at homotransplantation.

Further experimental studies, especially those conducted by Guthrie on hens, showed that autografts functioned for varying periods up to a year, with gradual diminution and finally complete cessation of function. The microscopic examinations revealed changes in keeping with the clinical manifestations of function.

Encouraged by the results obtained in autotransplantation, investigators began to study anew the possibilities in homotransplantation and heterotransplantation. A few successful results were obtained for varying periods up to a year and a half after homotransplantation in sheep (Woronoff). On the whole, however, the evidence indicates early degeneration and fibrosis of the ovarian grafts in the great majority of experiments. Heterografting of the ovary almost invariably resulted in early failure.

An aspect of ovarian transplantation, that is as yet of scientific interest only, is the grafting of the organ to a male of the same species. In this investigation, the question of viability of the transplant is of secondary interest, the main purpose being to discover whether the characteristics of the male may be altered by absorption of ovarian substance. The results were in doubt until Steinach demonstrated the presence of feminine characteristics in castrated male animals in which ovaries had been grafted. The reverse procedure had been successfully carried out many years before by Hunter.

Transplantation of the ovary in the human being has been practiced in many cases, yet definite conclusions cannot be drawn from most of the work that has been done. There is such a wide difference in the psychic characteristics of individuals that absence of symptoms of the menopause should never be interpreted as the result of reimplantation of removed ovaries. There are but two criteria of the success of ovarian transplantation that can be depended upon. These are microscopic examination demonstrating viability of the transplant, and evidence of function as indicated by a continuation of menstruation or the advent of pregnancy. The latter is not sufficient proof unless there is indubitable evidence that all ovarian tissue had previously been removed. Most of the reports in the literature claim successful transplantation of the ovary because of continuation of menstruation. An analysis of these reports shows that they deal chiefly with the manifestations occurring shortly after operation, disregarding the fact that continuation of menstruation might well be due in such instances to an absorption of the elements of a disintegrating graft and not to a viable transplant.

One should, therefore, be very cautious in accepting statements of successful ovarian transplantation, either autoplastically or homoplastically performed, unless there is the evidence of prolonged viability of the graft. Analyzed in this sense, we are unable to discover a single case in the literature of successful autotransplantation or homotransplantation of the ovary in the human being, the proof of which is incontrovertible. All that can be said at the present time is that there are a few instances in which the evidence points strongly towards persistence of function of ovarian autografts. There are an even smaller number of homografts concerning which the same statement may guardedly be made.

The Kidney.—In contrast to the grafting of other organs, the transplantation of the kidney involves transference of the whole organ. Another feature peculiar to the kidney alone is the fact that the organ, as far as known, has only an excretory function. The results of kidney transplantation may be more accurately interpreted than those of most other organ transplants, because the question of retained functioning fragments does not arise and because life cannot continue with a single transplanted kidney unless it functions.

Transplantation of the kidney is, therefore, a modern aspect of organ transplantation, since it must depend upon blood-vessel anastomosis. Earlier studies with transplants of portions of kidney tissue are of no present-day interest. The first efforts at grafting the kidney with maintenance of its blood supply were made by Ullmann, with only transient success. Carrel and Guthrie, in 1905, demonstrated beyond any question that successful autotransplantation of the kidney was possible by means of the method of vascular suture they introduced. They appreciated the fact that the transplanted kidney was exposed to the danger of necrosis because of thrombosis of the vessels and of ascending infection of the ureter. Carrel, therefore, practiced transplantation of the entire renal system, "transplantation en masse," a procedure that is of great scientific interest but of no practical significance.

Turning to Carrel's results in transplanting the kidney alone, it is seen that only immediate successes were obtained when the kidneys were removed and reimplanted at a single operation. On the other hand, absolute success was the outcome in one experiment when one kidney was transplanted in the first stage and the other kidney removed at a second operation. This dog lived with its single transplanted kidney for more than two years.

Others have succeeded in autotransplantation of the kidney since that time, demonstrating that it is possible for the solitary transplanted organ to function normally for an indefinite period. The persistence of normal function in an organ detached from its nerve supply is only to be explained on the basis of the presence of a potent autonomic nervous mechanism and this must be assumed to be the case for the transplanted kidney (see Chapter I). That all autotransplantation experiments with the kidney might succeed was not to be expected. From the reports that have appeared, it is quite evident that they have failed in the great majority of attempts.

Before turning to the subject of homotransplantation of the kidney, the epoch-making result obtained by Zaaijer should be mentioned again (see Chapter I). He reported a dog alive and well with a solitary kidney that had been transplanted to the thigh by blood-vessel suture more than six years before. From the description of the result there is every reason to believe that this animal will live the full span of life with its autotransplanted kidney.

Although experiments in autotransplantation have proved the transplantability of the kidney, they are, of course, of no practical significance in human surgery. Only in the most unusual circumstances could the question of a transplantation of the patient's own kidney arise. The attention of investigators naturally turned, therefore, to homotransplantation and heterotransplantation of the kidney. Decastello was the first

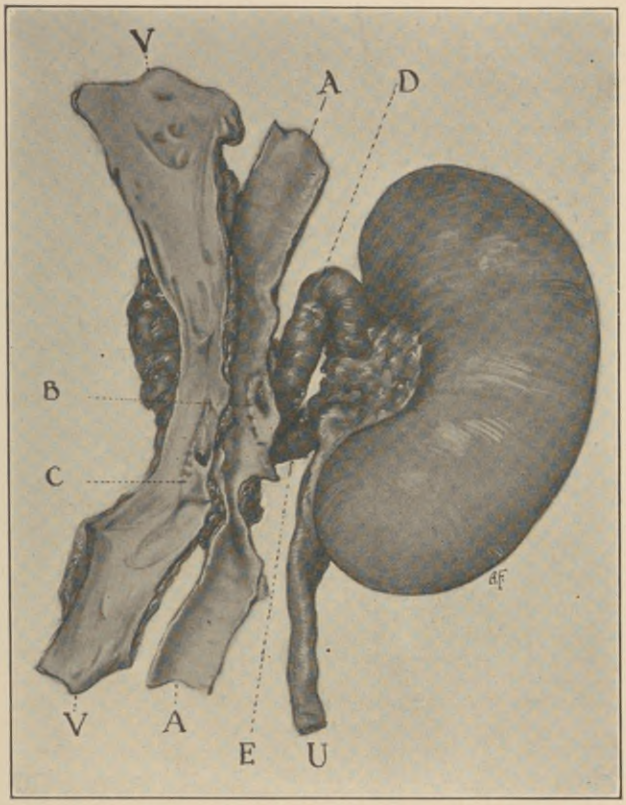


Fig. 103.—Drawing of Heterograft of Lamb's Kidney Transplanted into a Patient's Femoral Vessels, Nine Days after Operation (hardened specimen).

The femoral artery, *A*, and femoral vein, *V*, of the patient have been laid open to show the end-to-side anastomoses. The opening of the renal artery is seen at *B*, and of the renal vein at *C*. The renal artery, *D*, is much longer than the renal vein, *E*. The ureter, *U*, is collapsed.

to conduct experiments in the former, and Ullmann the first in the latter field. The results of these and other experiments can be briefly summarized. There is not a single instance in which the animal survived with the transplanted organ as the sole kidney. In a few experiments, the graft showed some evidence of transient viability, when the animal's own kidneys were not removed. The usual result of homotransplantation has been death from necrosis of the graft, although shrinkage and absorption of the transplanted kidney occasionally took place. These unfavorable phenomena in the graft may occur with intact anastomoses and adequate blood supply to the organ. I have been impressed by this significant fact in some recently conducted experiments in homotransplantation of the kidney. In heterotransplantation, an early thrombosis of the vessels of the graft usually occurred (see Chapter VII) to be followed by gangrene of the kidney and death.

No attempt at homotransplantation of the kidney in the human being has been reported. It is surprising that, despite the results of experiments, the only efforts that have been made in the human being have been with heterografts. The reported cases are as follows: In the first case, Ullman (1902) was unable to complete the operation. Jaboulay tried heterografting in two cases, using a pig's kidney in one patient

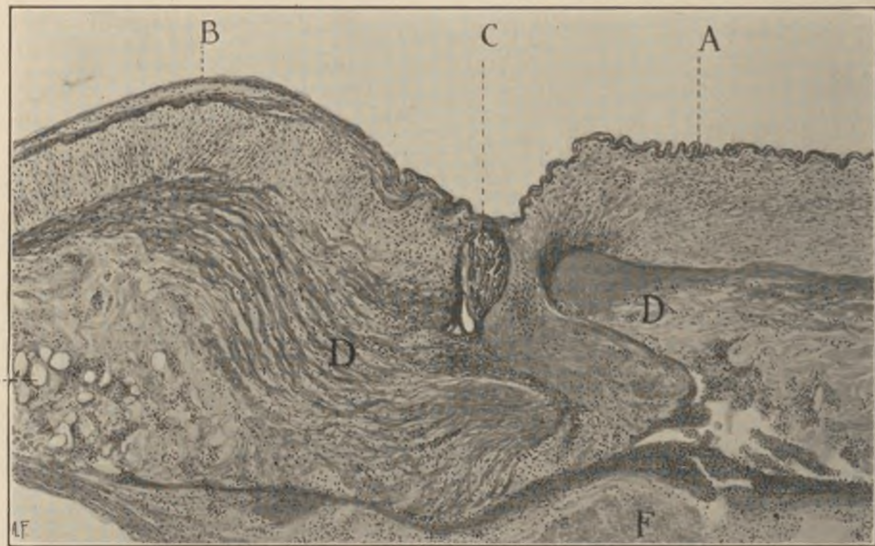
E.


FIG. 104.—SECTION THROUGH ANASTOMOSIS BETWEEN FEMORAL ARTERY AND TRANSPLANTED RENAL ARTERY.

A, human vessel. *B*, lamb's artery. *C*, silk suture, indicating site of junction. *D,D*, connective tissue on both sides of anastomosis intimately fusing with the ends of the vessels. *E*, adherent fat. *F*, blood-clot undergoing organization. Note the retention of the elastica of the heterograft and the absence of signs of degeneration.

and a goat's kidney in the other. The transplants, attached to the brachial vessels, became necrotic and had to be removed after three days. The only other reported case I have found is Unger's transplantation of an ape's kidney, its vessels being sutured to the femoral vessels of a patient suffering from an advanced nephritis. Death occurred thirty-two hours after operation, no urine escaping from the transplant in the interval. The animal kidney showed much less damage than is ordinarily seen after heterotransplantation, parts of the parenchyma being normal.

In a recent case of poisoning by bichlorid of mercury, I attempted a heterotransplantation of the kidney. There had been almost complete anuria for three days and the prognosis appeared hopeless. I believed that a transplanted kidney that would function temporarily might aid in tiding the patient over the period of urinary suppression. Unfortunately, a human kidney could not be obtained and an animal graft had to be employed. The patient's blood was tested against the blood of several lambs and the animal that showed relatively little hemolysin for the patient's red blood-cells was selected. This animal was anesthetized, bled, and the kidneys, with attached segments of aorta and vena cava, removed under aseptic precautions. The right kidney, which could be perfused more readily, was chosen. The aorta and vena cava were trimmed to make small elliptical flanges about the mouths of the renal vessels. An end-to-side rather than an end-to-end anastomosis between these and the patient's vessels was decided upon for two reasons: first, if thrombosis occurred, thrombi would not be directly in the blood

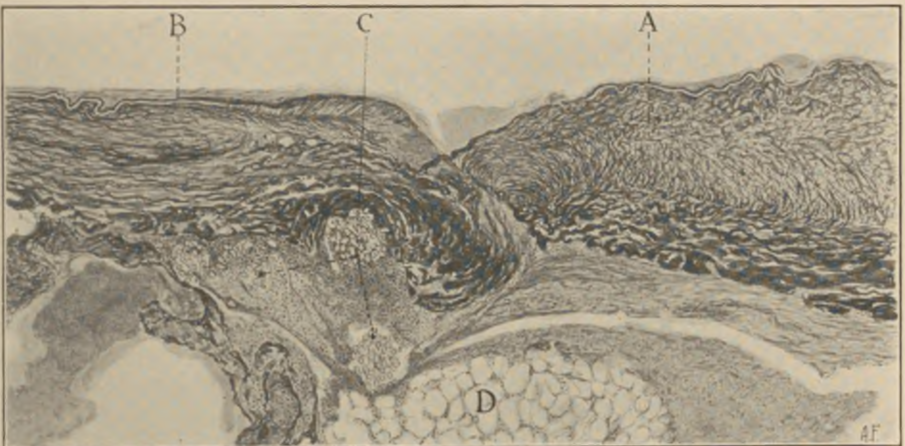


FIG. 105.—ANOTHER SECTION THROUGH THE ARTERIAL ANASTOMOSIS, VAN GIESON STAIN.
A, human artery. *B*, transplanted artery. *C*, silk sutures. *D*, adherent fat. Connective tissue bridges the gap and is massed at the site of fusion between the vessels.

stream; secondly, the transplant could be removed without necessarily interfering with the blood supply of the extremity. Under local anesthesia, the femoral vessels of the patient were isolated in the lower part of Scarpa's triangle. With the customary technic (see Chapter VII), lateral defects were made in the femoral artery and vein and the segments of aorta and vena cava (about the mouths of the renal vessels of the transplant) were sutured into the defects. Upon the release of the clamps on the femoral vessels, circulation of blood through the kidney was observed. The ureter was sutured to the lower angle of the wound.

There was no untoward reaction after operation. The general condition was fair and the temperature remained at or near normal until seven days after operation, when a bilateral lobar pneumonia developed, the patient dying nine days after the transplantation. The wound remained free from infection. The day after operation, there was an escape of small quantities of blood-tinged fluid. This had a urinous odor on several occasions until the sixth day, when the escape of fluid became much more scanty and was no longer of a urinous odor. It was impossible to collect enough fluid for examination for urea, etc. Two specimens, however, showed the presence of mercury. Whether or not the transplanted kidney really functioned at any time thus remained undetermined. The function of the patient's kidneys after operation is of interest. Two ounces were voided the day of operation and about this amount for the next three days. Rapid increase in output then began, up to a daily total of thirteen ounces at the time of death.

The autopsy disclosed the usual lesions of poisoning by bichlorid of mercury; the bilateral lobar pneumonia was the immediate cause of

FIG. 106.—SECTION OF TRANSPLANTED KIDNEY.

The profound degeneration of the renal elements is seen, the glomeruli being shrunken and the tubules staining very faintly. Note the capillary distended with blood and the well-preserved small artery.

death. There was no infection in the operative field. Gross and microscopic examination showed the absence of thrombosis at both end-to-side anastomoses. Microscopically there was very satisfactory repair between the transplanted and the patient's arteries and veins; and the rapid degeneration of the heterografted vessels, that had been anticipated, was not seen. In fact, the artery and vein revealed little if any evidence of degeneration. Thrombosis was present in both transplanted vessels in sections taken near the kidney, but whether this was antemortem or postmortem could not be determined. The transplanted kidney was of approximately normal size, but showed profound degeneration, all the component structures with the exception of the blood-vessels staining faintly. There was no evidence of infection in numerous sections from different parts of the organ. Only in sections taken at the surface was any infiltration by polynuclear leukocytes to be seen.

In this case, a definite conclusion cannot be drawn as to whether or not the transplant functioned as such at any time. It proves, however, that a heterografted kidney in the human being does not necessarily become gangrenous and that the procedure is, therefore, not necessarily a dangerous one, as had been supposed. It also demonstrates that thrombosis or hemorrhage at the anastomosis is not inevitable. I believe that this case report should turn attention anew to the problem of homotransplantation of the kidney.

The Parathyroid Glands.—It was not until experiments with the transplantation of parathyroid glands had been tried that their physiological significance was appreciated. Although von Eiselsberg's studies were not directly concerned with the transplantation of the parathyroids, relatively little has been added to his fundamental experiments performed in 1892. In transplanting a thyroid lobe, he found that parathyroids as well were included in the graft. Upon removal of the opposite lobe, manifestations of tetany did not appear. Tetany and death ensued, however, when the grafted thyroparathyroid was detached. Von Eiselsberg demonstrated, at the same time, that the transplantability of the parathyroid was greater than that of the thyroid, degeneration being evident to a lesser degree in the parathyroid after transference of the double graft.

The first experiments in transplanting the parathyroids alone were performed by Generali and Vassale with doubtful results. Cristiani demonstrated that parathyroids autoplastically grafted with thyroids remained viable for years, and the contrast between parathyroid and thyroid in this respect has been emphasized by later investigators. These efforts were, for the most part, in the direction of homotransplantation and heterotransplantation of parathyroids. In experiments conducted by Pool, transient successes were encountered in the former, failure in the latter. Halsted, on the other hand, described successful results, as evidenced, chiefly, by maintenance of function (absence of tetany) after homotransplantation. The work of Erdheim at one time appeared to establish successful homotransplantation of the parathyroid glands, on the basis of maintenance of calcium metabolism, but this proof is no longer considered conclusive. It is unnecessary to review all the attempts made to transplant the parathyroids homoplastically. There is no proof as yet of any but the most transient success.

Von Eiselsberg was the first to attempt homotransplantation of the parathyroid glands in the human being. Functional improvement was seen in cases of acute and chronic tetany occurring after thyroparathyroidectomy. Since that time, the procedure has been employed in a number of other cases with apparent benefit, notably in the case described by Pool. Analyzing all the reported results, it may be said that, in some instances, reports have been made too soon after operation to render a satisfactory estimate of the effects of the transplantation.

In others there were diminished grades of tetany that may have subsided spontaneously. Finally, it has not as yet been proved that the transplanted parathyroid is the only one present in patients suffering from postoperative tetany. The possibility of parathyroid rests can never be excluded without autopsy, and, as in thyroid transplantation, the results may be due to stimulation of or rest given to the patient's own parathyroid by absorption of the transplant, and not to retention of viability. These theoretical considerations, indicating that there is no established proof of prolonged viability of parathyroid homografts, must not blind one to the fact that practical results have been achieved. Homotransplantation of parathyroid glands has certainly some measure of clinical value in the treatment of postoperative tetany.

The Testicle.—In a study of the function of the testicle, Berthold initiated the work that has been done on transplantation of the organ. It early became evident that the combined internal and external secretory function of the testicle led to great difficulties in its transplantation. Few attempts have been made to maintain both in grafting experiments. The generative function has never been obtained by testicular transplantation. On the other hand, autotransplantation of the testicle has resulted in retention of male characteristics as compared with castrated controls. In some of these experiments, the interstitial cells of the transplants were found to have retained their viability. The same observation was made in a few experiments with homografts.

Considerable interest has been attracted by the few reported cases of homotransplantation of the testicle in the human being, a procedure inaugurated by Lespinasse. His patient had suffered the accidental loss of both testicles, with consequent impotence. Thin sections of a normal testicle were grafted into the abdominal wall and scrotum. A prompt return of potency followed and was maintained for the two years the patient was under observation. Other cases have been described in which return of function and of secondary male characteristics has occurred. The reports of cases do not as yet warrant conclusions as to the clinical value of homotransplantation of the testicle. The operative procedure has proved satisfactory clinically in a few instances and can properly be considered worthy of trial in suitable cases.

The Adrenal Gland.—The first adrenal transplantation was made by Canalis, in 1887, while conducting experiments undertaken to ascertain the function of the gland. From these and other experiments, it was learned that the adrenals were essential to life. The earliest systematic study of the results of transplantation, made by Boinet, demonstrated prompt death of autotransplants in every experiment. It is safe to predict that adrenal transplantation is not likely to be successful because of the intimate linking of the gland with the nervous system. Proof of this was offered by de Dominici, who showed that the adrenal function was lost when the nerve connections of the organ were divided and that this was true despite the fact that microscopic examination of the adrenal disclosed no abnormalities. Later experimental work appeared to establish a difference in transplantability between the cortical and medullary portions of the gland, the former showing somewhat longer persistence than the latter. On the whole, however, all the evidence points clearly to total inability of adrenal grafts to remain viable or to act as substitutes for any loss of secretion that may have occurred. In homotransplantation the best results have merely been the retention of function for a few days, after which adrenalin, derived chiefly from the medullary portion of the gland, was no longer available to the organism.

Despite the negative results of experimental work, adrenal grafting has been attempted in a few cases in the human being for the treatment of Addison's disease. Heterografts were used, and, as might have been anticipated, no effect was produced. In fact death ensued promptly in two cases, possibly as a result of the introduction of foreign protein material.

The Pancreas.—The presence of a combined internal and external secretory function presents the same difficulties in whole gland transplantation of the pancreas as noted for the testicle. Here, too, the problem has been confined chiefly to transplantation of sections of the pancreas with the object of supplying their internal secretions to the organism. The procedure was introduced by Minkowski, in 1892. His classic experiment is still quoted widely as a demonstration of the viability of pancreas grafts. A portion of the pancreas was transplanted to the subcutaneous tissues. At a later stage, the rest of the pancreas was removed without glycosuria resulting. Glycosuria followed directly upon the removal of the graft. The interval between removal of the remaining pancreas and of the graft was so short, however, that the experiment does not prove more than absorption from a graft that may have been degenerating.

Later experimental studies succeeded in demonstrating transient viability of autografts of pancreatic tissue. Whether prolonged viability exists is difficult to determine, for retention cysts appear about the excretory ducts with resulting compression and destruction of the Langerhans' cells. Homotransplantation of pancreatic tissue cannot be carried out for the same reason, and thus there are no clinical possibilities for pancreas grafting at the present time.

The Hypophysis.—After the respective function of the anterior and posterior lobes of the hypophysis had been approximately determined, there followed a series of experiments involving the autotransplantation of the whole gland and of various portions. Crowe, Cushing and Homans demonstrated transient viability of autografts in a small proportion of their experiments and in these, too, the temporary absence of manifestations referable to hypophyseal deficiency was probably due to absorption from the disintegrating transplants. No better results were obtained by other investigators. The results following homotransplantation, the only method that might be clinically applicable, do not warrant serious consideration of the method in surgical practice at this time.

The Thymus.—With our present limited knowledge of the function of the thymus, it is difficult to determine whether the manifestations ascribed to lesions of the thymus are due to hyperactivity or hypoactivity of that organ. This essential element being in doubt, and the results of transplantation of the gland being extremely uncertain, there is no clinical indication for thymus grafting. Klose and Vogt are chiefly responsible for statements concerning the viability of autografts of the organ. It would appear that, under favorable circumstances, grafts may heal in place temporarily with a supposed persistence of function as evidenced by control of bone growth. Presumed transient viability was seen more rarely after homotransplantation.

Transplantation of Other Organs.—Experiments with transplantation of the *spleen* were practiced chiefly during the time that the spleen was thought to be an organ essential to life. It is of purely theoretical interest to note that autografts of spleen have been successful over long periods of time with and without the aid of vascular suture. Homotransplantation of the spleen is followed by necrosis and fibrous tissue replacement. Experiments have been conducted in massive transplantation of the *heart, lung, large intestine,* etc., with unsatisfactory results, and are of no clinical interest. Finally, grafting of the *female breast* may be mentioned as an instance of successful experimental transplantation. The whole breast has been transplanted subcutaneously as well as to the surface of the spleen. Secretion of milk in the transplanted breast has been observed, when pregnancy occurred, many months after the transplantation.

The Transplantation of Toes and Fingers.—For many years it has been known that almost completely or completely severed portions of fingers could be successfully sutured back in place. Numerous experiences have been recorded in which healing has occurred even under adverse circumstances, especially in young individuals. Naturally, therefore, attention was turned toward deliberate efforts to transplant portions of toes or fingers as substitutes for missing fingers. Nicoladoni, in 1898, was the first to outline the principles and procedures that should be carried out. He suggested two methods for the plastic replacement of a lost thumb. The first consisted in a plastic-cuff-flap of the chest wall, to which the stump of the thumb was attached, and in which a sliver of bone from the tibia was inserted in order to give the necessary support. The second method for the replacement of a thumb was a pedicled transplantation of a portion of another finger or of the second toe on the same side.

Various plastic procedures on the structures of the hand have been carried out with modifications of Nicoladoni's first and second methods, oftentimes with most satisfactory results. They cannot be detailed, however, for we are only concerned here with the transplantation of whole toes or fingers. The few attempts at *free* autotransplantation and the single effort at pedicled homotransplantation have failed, and the only results that can be discussed at the present time are those following autotransplantation of part or all of the first or second toes by a pedicled flap (second method of Nicoladoni).

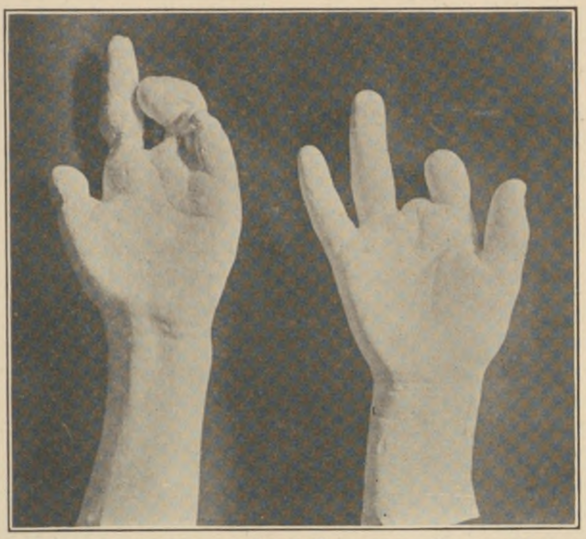


FIG. 107.—PLASTER MODELS OF RIGHT AND LEFT HANDS OF A CASE OF CONGENITAL DEFORMITY.

The third finger of the right hand is missing, the second finger lacks the distal phalanges. Of the left hand, the last three fingers are represented by fused and deformed stumps, the other fingers are also deformed.

FIG. 108.—FIVE MONTHS AFTER TRANSPLANTATION OF SECOND TOE FOR MISSING MIDDLE FINGER OF RIGHT HAND.

Separation of the fused finger stumps of the left hand has also been carried out as a preliminary to additional plastic procedures.

Of the ten cases that have been reported, all but one were operated upon for the replacement of a portion or all of a missing thumb. The single exception is a case reported by von Eiselsberg, in which part of the second toe was transplanted as a substitute for the lost distal two thirds of an index finger. It is of interest to note that complete failure occurred in only one of the ten cases in the literature. There may, of course, be failures that have not been placed on record, but one gains the impression that a satisfactory result can be justifiably anticipated in favorable cases. A successful outcome is one in which the transplant heals in place without untoward manifestations and has a pleasing cosmetic effect. The ideal result would be normal function of the transplanted member, but this has not as yet been attained. In a few instances, some degree of active motion has existed. As to the cosmetic result, it is impossible to determine if the outcome has been completely

FIG. 109.—X-RAY OF RIGHT HAND BEFORE TRANSPLANTATION OF TOE.
Note the retained portion of the proximal phalanx in the missing finger.

FIG. 110.—X-RAY OF RIGHT HAND FOUR MONTHS AFTER TRANSPLANTATION OF TOE.
The architecture of the phalanges of the transplant is well preserved.

satisfying in most of the reported cases. There can be no question, however, of the improvement over the preëxisting condition in every instance. Slight if any disturbance has apparently followed the loss of part or all of the great toe, although some discomfort would ordinarily be anticipated as the result of its sacrifice. We may, therefore, conclude that the transplantation of the great toe is a justifiable procedure for the loss of the thumb in a properly selected case.

The principles of operative technic are outlined in the case of transplantation of the second toe for a missing middle finger that I now wish to report. To my knowledge, it is the first instance in which an attempt has been made to replace a completely lost finger other than a thumb. Replacement of a partly missing finger was successfully carried out in one case, that reported by von Eiselsberg, to which reference has been made.

The patient, a girl seven years old, was congenitally afflicted with the deformities of her fingers. The etiology is unknown, but the partial constriction about some of the fingers suggests the diagnosis of amniotic bands. The appearance of the hands can be judged from the plaster models (Fig. 107). At the first operation, the fused stumps of the third, fourth and fifth fingers of the left hand were separated by plastic incisions. The chief purpose in first doing this operation was to gain an idea of the type of repair of the skin about the finger stumps. This proved to be satisfactory and the transplantation of the second toe for the absent middle finger of the right hand was decided upon.

An inspection of the plaster model will show that the distal portion of the index finger is also missing. Despite that fact, it was evident that a transplanted toe would not be long enough to extend as far as the tip of the short index finger. I therefore determined to graft along with the toe a portion of the metatarsus with enveloping soft parts. By testing various postures, I learned that juxtaposition between the left foot and right hand would be less uncomfortable than one between the right foot and right hand. Accordingly a plaster casing was prepared to approximate the left foot to the right hand, the left leg being in flexion and external rotation at the hip, the back flexed, and the right arm adducted and brought forward.

At the operation, the skin over the stump of the missing finger was reflected laterally, the end of the bone freshened (see Fig. 109 for the appearance of the bone), and the ends of the flexor and extensor tendons of the finger found and isolated. An incision was then made across the web between the first and second toes of the left foot and deepened along the dorsal and plantar surfaces of the foot. The dissection was carried to the metatarsal bone, which was divided about 2 cm. behind its head. The flexor and extensor tendons of the second toe were then divided at this level. The dissection was continued until the toe with metatarsal tissues was free except for the pedicle of skin and vessels on its lateral aspect. Guide sutures were placed through the tendons, and foot and hand were brought together. By interlacing fingers and toes, the parts could be readily held in apposition. The tendons were brought together without difficulty, the bones sutured with chromic gut, and the skin flaps with silk. The plaster cast was applied after arm and leg were fixed together by adhesive.

The patient was uncomfortable and restless in the encasing dressing, and partial separation of the sutures was noted on the third day after operation. The remainder of the wound healed well, however, and separation of the pedicle was carried out two weeks after the first operation.

At the second stage, the head of the metacarpal bone was unexpectedly found to make too great a prominence on the palm for a satisfactory cosmetic result. It was therefore sacrificed. The anastomosis between the tendons was damaged in doing this and I realized that it was an error to have sutured the extensor tendons at the first stage. There is no difficulty with the flexor tendons but suture of the extensor tendons should be deferred, I believe, to the second stage. The toe was freed by cutting across the web between it and the third toe. After excision of some of the fatty tissue that is found on the plantar surface of the foot at its junction with the toe, the skin of the transplant was loosely sutured to that of the hand. The wound of the foot was strapped, obliterating the dead space left by the loss of the toe and the adjoining metatarsal tissues. A splint was applied to the hand for the support of the transplant, but open dressings with the use of dry warm air were instituted from the outset.

After the first few days, the circulation in the transplanted toe became good and has remained so up to the present time, six months after operation. Gaps where the skin was not approximated healed by granulation tissue. There have been no untoward manifestations referable either to the foot or to the transplant. The skin over the latter is of a slightly more dusky appearance than the adjacent skin. The nail shows a retarded but otherwise normal growth. Sensation has almost completely returned throughout. Function is limited to slight flexion and extension. The cosmetic result is satisfactory.

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INDEX OF AUTHORS

INDEX OF SUBJECTS

(1)