A LECTURE

ON

THE DEVELOPMENT OF THE OSSEOUS CALLUS IN FRACTURES OF THE BONES OF MAN AND ANIMALS,

DELIVERED BEFORE THE

ANATOMICAL AND SURGICAL SOCIETY OF BROOKLYN,

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THE DEVELOPMENT OF THE OSSEOUS CALLUS IN FRACTURES OF THE BONES OF MAN AND ANIMALS.[1]

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THE results of my investigations upon the repair processes in fractures of the bones of animals and man, are quite different from the teachings which I had received, or my previous accepted conclusions. My studies in this direction were prompted by my clinical observations upon the repair of fractures under various modes of treatment, and especially from my belief, that after careful adaptation and complete rest secured with plastic splints, there occurred, under favorable circumstances, a primary union in bone not unlike that taking place in the repair of superficial wounds. In one or two monographs upon the treatment of fractures, published some years since, I inculcated this thought. I have availed myself of the great profit derived from the teachings of Comparative Pathology, and have selected the rabbit as the most convenient animal from which to make decalcified injected specimens. First of all, I would give full share of credit to my friend and co-laborer, Dr. A. F. Holt, of Cambridge, whose pains taking and carefully prepared microscopic sections will be appreciated by all engaged in this difficult field of histological research.

[1] A lecture delivered before the Anatomical and Surgical Society, December 7th, 1880.

From the time of Galen, the fathers accepted his teaching that "the gelatinous moisture," as he called it, which surrounds the fractured extremities of a bone, was the material that formed the new osseous growth called callus.

Dupuytren, enlarging upon the doctrines taught by Galen and Haller, asserted that "nature never accomplished the immediate union of a fracture save by the formation of two successive deposits of callus, one of which is derived from the periosteum, adjacent tissues and the medulla, while the other, formed perhaps from the broken extremities of the bone itself, is found at a later period directly interposed between their surfaces."

After the publications of Ollier, in 1859 and 1860, upon the osteo-genetic property of the periosteum, surgeons and anatomists were agreed in rejecting the doctrines taught concerning the formation of the callus, and maintained that the neo-formative process was due wholly to the periosteum. These were the teachings received during my pupilage.

One of Italy's most distinguished students, Prof. G. B. Ercolani, of Bologna, published in 1866 a monograph upon the repair of fractures, and gave as his conclusions that the extremities of a fractured bone took no part in the process resulting from which the osseous callus is formed, and that the periosteum near the fracture is a less important factor than is usually believed, oftentimes undergoing even a destructive process.

In 1867, Billroth, in his important investigations upon the regeneration of bones in fractures, closed with the following conclusions: [1]"If we now view the processes as a whole, we see that the cell infiltration in the bone itself, as well as in all the surrounding parts, aids in the formation of callus, and that hence the periosteum plays no exclusive osteoplastic role." This might have been concluded *a priori;* for if the

[1]Surg. Pathology, American edition, p. 181.

periosteum alone formed the external callus, as was supposed, the portions of bone free of periosteum, such as those places where tendons are attached to the bone, could form no callus, which is directly contradicted by observations. In normal growth also the periosteum does not, by any means, have the importance ascribed to it in the formation of bone, for we may just as correctly regard the layer of young cells upon the surface of the bone and extending into the Haversian canals as belonging to the bone, as to refer it to the periosteum. This distinguished surgeon arrived at these conclusions after much careful study upon dogs and rabbits.

From the most remote antiquity it has been known to surgeons that all about the place where a fracture of a long bone has occurred, there is observed in a few days a material of a gelatinous appearance mingled with a greater or less quantity of blood. This is elastic, becomes more firm, is smooth externally, and everywhere embraces the fragments. This is the so-called soft callus, and is destined to be changed into osseous substance. These neo-formative processes have been the subject of careful study by many investigators, from Galen to our own day. Differences of opinion have been held as to the origin of the neoplasm and the elements which share most actively in the new growth. Some have believed that it is derived from the blood and its coagulated elements. Others regard it as elaborated from the medulla of the bones; more recently the periosteum alone has been held as the active factor of reproduction. Again, after Billroth, these changes have been assigned to the bone itself. "This new material," he says, "is developed from the connective tissue of the medullary cavity of the canals of Havers, which proceeds from the surface of the fracture, meets the like tissue which comes from the other fragments, and is blended with it in the same way that the union of the soft parts is effected." This would be analogous to primary union in superficial wounds.

Influenced by his own researches in Comparative Pathology, Prof. Ercolani claimed, in 1867, that the periosteum was destroyed in the place where the soft callus was formed, and, as a consequence, it could take no active part in the formative processes. This was, in a measure, confirmed by Billroth, and both are now agreed that it is to a new periosteum, formed upon the soft callus from a thick layer of connective tissue, to which must be ascribed a very important function.

If there was error in Ollier's theory which made the formation of the callus depend upon that portion of the periosteum which is destroyed and absorbed, Billroth's teaching is also incomplete when, to the new-formed periosteum, he would attribute the development of the osseous substance to the callus, since this is the result of two equally indispensable conditions—namely, periosteum or ossifying organ upon the one side, and ossiferous organic elements upon the other. Wherefore, as the irritated periosteum finds in the exudation from its own vessels the ossiferous elements, so the new periosteum, which is under discussion, finds in the soft neo-plasm ossiferous elements, without which the new-formed periosteum, like the old periosteum in sound bones, though it repairs the waste of the bone, is yet inadequate to the reproduction of new osseous substance.

Ercolani says, "that comparative researches, moreover, will show not only that the new doctrine taught by Billroth on the formative process of the callus is erroneous, but also that no single principle is sufficient to explain the formation of the callus in the different cases of fracture. This would naturally differ not only in the long and the flat bones, but according as fractures of the long bones are simple or compound, and also in simple fractures, whether the fragments are maintained close together or apart from each other during the period in which the callus is formed."

Before proceeding to study in detail the importance of the several elements or tissues existing at the place where a fracture may occur, it is necessary to refer briefly to the normal development of bone, for it would seem a fair deduction to suppose that the repair processes in a fracture do not very widely depart from those of formation. Examine the growing bone of a very young child. The condyles are composed of cartilage, and the periosteum is continued from the shaft of the bone over the cartilage, the outer layers of which have assumed a fibroid character. This is the way in which the periosteum is formed, and it may be considered a fibro-cartilage developed out of the temporary cartilage, from which the shaft of the bone is produced. This newly formed fibro-cellular tissue, covering the developing bone, contains living cells of precisely the same nature as those from which the shaft is constructed, and in this manner the circumference of a long bone is increased, as layer upon layer of the cells ossify, arranging themselves into Haversian systems.

This vitalized matter, the germinal material of Beale, under favorable circumstances, surrounds itself with a soft hyaline substance which, as it increases in quantity, separates the nuclei of the original cells from one another; about the nucleus there is secreted, into the hyaline material, lime salts, and, so to speak, each cell becomes encased in a shell firmly fixed to its neighbor; thus the so-called osteo-blasts become bone corpuscles. This is the end of the development series, the highest possible form of osseous growth, and the integrity of its vitalized condition maintained by the nutritive supply furnished through the Haversian and canalicular circulation.

A priori, it would seem, that from cells thus encased and developed to maintain the integrity of firm support required in the osseous structure, little or no part could be taken by them in the process of repair. Their germinal matter is locked up, so to speak, in an earthy encasement, and cannot sub-divide for the production of new cell growth; increase of material in the circulatory system of the bone would, within a certain limit, only increase the development of earthy material to the expense of the cell itself or the intervening canals, as, for example, the so-called eburnated exostosis, and exceeding this, as in other tissues, would react to the death of the cell itself—the very changes that take place in necrosis.

In the medullary canal of long bones there is found a network of cytogenic or adenoid tissue continuous with that of the endosteum, its meshes being filled with a vast number of corpuscles which, histologically and, it is claimed, functionally, are not unlike those of the spleen. Several excellent observers maintain that this plexus of adenoid tissue is the commencement of a lymphatic system in bones. We cannot doubt these structures play an important part in certain pathological changes of the bones, and it is a fair inference to believe they modify and control, to a certain extent, their normal nutrition and—when called into especial activity after injuries—the processes of repair. This is very probably an active factor in the production of fatal results which follow septic poisoning after compound fractures.

The material forming the soft callus in the first days after a fracture is furnished from the blood of the lacerated vessels as well as the connective and other tissues injured, including those of the medulla and Haversian canals. Since these elements are furnished from these various sources and may not be unlike in character, it is impossible, in the mass, to distinguish them as to their origin, or to say what part they take in the process of restoration. It may be assumed that the exuded blood is not a very important factor;

for we learn clinically that a copious effusion of blood always delays, instead of assisting, in the repair. And thus we infer that the white globules, as well as the red, undergo a process of absorption, and are not especially valuable agents of regeneration, and that, even when the amount of effused blood in the callus is small, it is an entirely secondary and unimportant factor in the formative process. It must be conceded that the part which the medulla takes in the restorative changes may be much more significant than that of the effused blood; for it cannot be denied that the exudation from the connective tissue and its vessels assumes distinctive importance. This is shown by ossific depositions in the medulla after artificial irritation; also in some instances by extensive ossifications of the medulla in fractured bones, which for a long time impede the re-establishment of the old medullary cavity, and by the consolidations of fractured flat bones, owing to the ossification of their spongy substance. However, observation clearly shows that in the long bones, in some cases, the part which the medulla takes, though very considerable, is yet not indispensable for the formation of the callus, since it is found and very solidly formed in the bones of birds, which have no medulla. Neither has it any importance in man or animals when the fragments of the broken bone are kept apart, since they are then re-united by means of an osseous bridge entirely external. The surfaces of the separated fragments remain inert and without ossification of the medulla within their medullary cavities.

Through the kindness of Prof. Hyatt, of the Boston Natural History Society, I have selected two specimens of the many at my disposal, which show the formative processes of repair in birds. The first is the ulna of the swan. Held as it was with very little displacement, resting upon a veritable water-bed, the repair has gone on with singular effectiveness and symmetry, leaving so little deformity that it was by no means certain that a fracture existed until the bone was sawed open. The other specimen—the humerus of a turkey—shows the great deformity which ensued, and the union which has taken place is by an osseous development cementing the fragments separated a considerable distance from each other. The femur of a cat, a beautiful specimen from the Jeffries Wyman collection, exhibits great displacement of the fragments with shortening. We fail to observe not only any trace of neo-formative process upon the borders of the medullary cavity of the bone, but the fragments subjected to an actual atrophy of the osseous substance, present smooth and rounded ends instead of sharp and cutting angles. Hence, we may conclude that the part taken by the medulla in the neo-formative process of the callus in the long bones, although usually important, is by no means necessary, and, like the white globules of the blood, occupies a place of secondary importance. These examples of osseous callus in the human species are most frequently met with in the clavicle and femur, in which great displacement of the fragments is more common.

In the Peabody Archæological Museum of Cambridge are preserved several long bones from a pre-historic age which are interesting, not only as illustrating the formation of the osseous callus in bones, the extremities of which are widely separated, but teach, so far as these specimens go, that the art of surgical appliance to fractures was not well understood by the mound-builders of the West.

Since the publication of Prof. Ercolani, before mentioned, my attention has been called especially to fissures in bones, or so-called partial fractures, because the significance given by him to the changes which supervene was to me new and peculiar. They show that it is not possible to accept the fundamental part of the doctrine held by Billroth in regard to the formation of the callus. In his monograph, published in 1878, Ercolani figured several old fractures of the bones of the horse, which exhibit to a remarkable degree the absorptive changes which take place in the line of the fissures, and stated that he thought the bones of the horse are much more liable to undergo these changes than are those of man. He described, however, a human skull, in which these changes had occurred in a marked degree.

Believing if processes of absorption supervene in fractures of human bones they must be very rare, I have taken the occasion to examine several of the largest collections in the United States, and have failed to find any marked illustrations of absorptive changes occurring upon the line of fissures in any of the long bones. I have found, however, a number of old fractures in the flat bones which exhibit very well these processes.

If it be true, as Billroth taught, that the Haversian system is the important factor of repair, we ought to find the most favorable condition possible for this in partial fractures or fissures of the bone; for in these we have no displacement of fragments, and the injury to the periosteum is reduced to the minimum. Yet, it is precisely here a process of absorption frequently supervenes and the fracture is never completely repaired.

I would express my great obligation to Dr. F. H. Whitney, Curator of the Warren Anatomical Museum of Boston, for the loan of several specimens, showing these changes which hitherto have passed without explanation or even special observation. The specimen numbered 983 is catalogued simply as a fracture of the coracoid process of the scapula, contributed by Dr. J. C. Warren, 1847. A more careful examination of it shows that the edges of the fracture which had extended into the glenoid cavity have undergone no effort at repair; yet, upon the superior border of the neck, there is an abundant formation of new bone, filling the supra-scapular notch and extending along a fissure running nearly the whole length of the supra-spinous fossa. Upon the anterior side an extensive periostitis had supervened, yet, instead of a deposit of new bone, there is a marked absorption running the whole length of the fissure. No. 973, presented in 1859 by Dr. R. M. Hodges, is a cranium, upon which are seen the effects of an old fracture. There is a cleft in the right parietal bone, about five and a half inches long, one inch at the widest part, irregular in shape and horizontal in its direction; anteriorly there extends from this opening to beyond the median line a fissure that has the appearance of a fracture. The internal surface is much more irregular and has a peculiar eroded look for some distance beyond the depression upon the external table. Posteriorly a crevice, with erosion and much roughness extends from the opening downward into the occiput, and is more clearly defined internally than upon the outer surface. There is no deposit of new bone, the edges of the large opening have a smooth appearance, and the structure of the whole bone is quite healthy. This specimen was from a dissecting-room subject, about thirty-five years of age. There was a deep cicatrix externally corresponding to the large opening, and anteriorly there seemed to be a smaller one. It was a question whether this might not have been a case of burn or disease, but it appeared, on the whole, more like a fracture. The specimen, number 974 of the catalogue, is also of great interest, as it shows an old fissure of the occiput on the median line, entering the occipital foramen, which is enlarged considerably posteriorly. Much absorption has taken place along the line of the fissure, to which is evidently due the irregular enlargement of the foramen.

Equally important for study is a skull furnished me by the courtesy of Dr. J. C. Warren, from the private museum of his father and grandfather. It is labelled, "Soldier, Napoleon's army, wounded at the battle of Pyramids; died at Hotel des Invalides, 1832." Thus it appears the man survived his injuries, probably sabre fractures, thirty-four years. It is remarkarble on account of a depressed fracture of the frontal bone, a little to the right of the median line, one and a half inches long, of U-shaped character, showing failure at union along its edges with considerable loss of substance from absorption. In the right parietal there is an old fissure, extending from the squamous suture upwards and forwards three inches, but only through the external table. In the left parietal, posteriorly, there is a fissure from near the median line through the temporal bone to the base of the skull, in part through both tables. The entire skull is very thin, the diploe being almost everywhere absent.

In the Medical and Surgical History of the Rebellion there is given a full plate illustrative of a specimen contributed to the Army Museum at Washington, by Assistant-Surgeon S. E. Ayres, as an example of sabre fractures of the vault of the cranium. The patient stated he had been wounded several years before by a blow from a sabre, and, since his recovery, although still in service, he had been subject to occasional convulsions. In one of these he died. There are to be seen multiple united sabre fractures of the os frontis and united linear fractures of both parietals, and disjunction of the coronal suture of the right side. Most of the fractures had penetrated the lamina vitrea which was much thickened in the vicinity of the injuries. Several detached fragments of the inner table had reunited, and exhibited an eburnated appearance. Along the sagittal and coronal sutures and in the neighborhood of the incised fractures, there were osseous deposits of long standing. Along the linear fractures marked absorptive changes have taken place. Another illustration of fissuring in bone is taken from part second of the Medical and Surgical History of the Rebellion. It is a gunshot injury of the left ilium, extending to within an inch of the acetabulum, to which it is connected by a deep fissure, the edges of which have undergone, in a marked degree, absorption. A periostitis had taken place all about the injury, except at its superior border where the bone is necrosed, yet there is not the slightest evidence of repair about the fissure.

These specimens plainly teach that in the cranial vault, where fissures occur without disturbance in bone, osseous callus is not deposited, but instead there are found very evident osseous clefts. These facts lead to the conclusion that the neoplasm which originates from the contents of the canals of Havers, cannot, of itself alone, possess a true osteoplastic value. The causes which would seem to have led to the absorption in a manner not unlike that seen upon the rounded ends of misplaced long bones, may be referred to the destruction or devitalisation of the periosteum at the place of injury, and will be discussed as we examine, in detail, the part which is taken by the periosteum in the process of repair.

Professor Ercolani stated, in 1866, "that repeated observations had demonstrated to him that the periosteum underlying the soft neoplasm surrounding the fractured bone, was shortly attacked by a complete process of destruction." In 1867, Billroth wrote "that the periosteum disappears in the new tissue and in the callus in the course of ossification." After this clear and precise statement, he asserted, "the periosteum has not a very important share in the formative process of the callus." When we remember the emphasis which he placed upon the osteo-genetic function of the irritative exudation from the Haversian system, we are led to believe he meant the periosteum in general, for he did not describe a metamorphosis of periosteum taking place in the callus, hence we conclude that he must refer to destructive changes when he stated that the periosteum disappears.

This is an important conclusion, and one to be carefully reviewed, even when taught by so illustrious a master. We may assume that it is an unquestioned fact that to the integrity of the periosteum corresponds the integrity of the bone which it covers, and that to lesions of the periosteum correspond alterations in the bone; also that a moderate degree of irritation in the periosteum suffices to determine an excessive production of osseous substance, while a serious and profound lesion of the periosteum produces an opposite effect, the devitalisation of the substance of the bone.

Let us compare these observations, so universally accepted, with the specimens before described. In these several examples, along the fissures there is found scarcely the slightest trace of neo-formation of osseous substance, yet a little way therefrom appears a more or less abundant deposit. It would seem a fair interpretation that in the place where the fissures of the bone occurred, the lesion of the periosteum was so serious as to produce a sudden cessation in its osteo-genetic function, while in the neighboring parts, where the irritating and inflammatory process became necessarily less severe, there the process of osseous neo-formation was active. If the injury to the periosteum in simple fractures or even fissures is followed by results so serious as to put an end to its osteo-genetic function, it must, in a yet larger measure, be true, in the more severe injuries and in compound fractures; this is abundantly proved in the long bones, either human or animal, which have consolidated with displacement of their extremities. We have already shown that the osseous substance at the apices in displaced fractures after a time undergoes a marked atrophy, and, in the series of microscopic preparations from the rabbit to be described presently, we think it is demonstrated that these changes by absorption of the old bone commence within a few days after the injury.

This is in direct evidence that the exudation from the Haversian system, as earlier remarked, has not, in these instances at least, an osteo-genetic function. From these observations and equally important ones derived from the study of fractures in flat bones, and especially from the demonstrations in the microscopic preparations referred to, it seems a conclusion from which there is no escape, that the periosteum at the place where the fracture occurs takes no part in the neo-formative process, but is actually destroyed. One following thus far in the analysis of the different factors which enter into the regeneration of bone, and finding that each may be excluded or considered non-essential, will be led to inquire what then is the physico-pathological process by means of which the callus is formed? This differs in a great measure according to the form of the bone, whether flat, spongy or long; the kind of fracture, whether simple or compound; and the position which the fragments of the bone assume and retain during the period of repair. The results of careful study of these processes in the long bones of the rabbit we now give as the best possible illustration of what we believe occurs in the long bones of all animals when placed under similar favorable circumstances. The series comprise fourteen animals from the third to the twenty-fourth day inclusive, all having been submitted to the same treatment. The animals were etherized, the leg fractured and at once secured in a plaster splint. They were then chloroformed at the desired period, a canula inserted through the left ventrical into the aorta, and blue gelatine solution was injected quite warm. After repeated experiments, Dr. Holt and myself have determined that the best means of injection is by the continuous stream under steady, but not too great, atmospheric pressure.

THIRD DAY.[1]

The preparations of the third day after the injury, the apposition having been nearly perfect, show very few marked changes. The edges of the fractured bone, which upon one border were considerably splintered, have scarcely altered, the neighboring vessels are not enlarged, and only a few red and white blood cells are to be seen. There is a small quantity of plasmatic fluid about the fractured ends, which, magnified five to six hundred diameters, is shown to be composed of fine granules. The Haversian system appears unaltered, and the periosteum is infiltrated with red corpuscles.

SIXTH DAY.

The changes from the third to the sixth day are instructive. There are seen a few blood vessels already formed in the new callus, which is distinct, and the exudate between the fragments is blended with the old bone. A nearly amorphous or finely granular material fills the interspace. This is under the most favorable conditions, as the fracture was not complete.

NINTH DAY.

The changes which have taken place in the specimen of the ninth day are of much greater importance. The blood effused into the medullary canal has been largely absorbed, and we see in the finely granular matrix loops of new vessels rapidly forming. Many of them are ectasic in character and inosculate with the medullary vessels. The borders of the fractured bone are somewhat softened and cemented by the same finely granular material, as seen in the specimens from the third and sixth days.

[1] The decalcified specimens were cut by Dr. Fisher's microtome, with the exception of a few recently made when Dr. Haile's freezing microtome was used. Both are very valuable instruments for the purpose, Dr. Haile's giving specimens of especial evenness and beauty. They are believed to be one-thousandth of an inch or less in thickness, and are mounted part in balsam and part in glycerine.

The vessels of the Haversian canals remain unchanged. The periosteum presents marked modifications at the side of the fracture; upon both borders of the bone there is a distinctly defined disintegration of the periosteum with absorption, less extensive where the fragments are in close apposition. Extending several lines in either direction there is an abundant deposit of the formative callus or grume of the earlier writers which infiltrates and incorporates into itself certain fibres of torn muscular tissue. This contains a few red and white blood cells. Upon one border of one of the preparations of this date there is an extensive fissure which shows no effort at repair, but, on the contrary, an active process of absorption has taken place upon the osseous borders and the interspace is filled with amorphous material. There is considerable displacement.

TENTH DAY.

The specimens of the tenth day are described because they exhibit the development of the so-called internal callus. There was no displacement of the fragments, and, hence, a less active periosteal development. The new material upon the medullary borders is distinctly ossific, and is carried forward in diverticula separated from each other by loops of vessels surrounded by a bed of germinal matter. Upon the inner border of the fractured ends there is a very considerable layer of cartilage cells. The capillaries are chiefly prolongations of the medullary vessels, although some are traced directly into the Haversian canals, and there doubtless inosculate with each other. The injected Haversian vessels are no larger than in the bone quite remote from the fracture, and the active part taken by the Haversian system, as claimed by Billroth, is not found. The medullary vessels in the vicinity of the fracture are considerably enlarged. There is also trace of the necrosis of the old periosteum and the overlapping of the new periosteal growth is well shown.

TWELFTH DAY.

The specimens of the twelfth day show beautifully the more perfectly developed series of vessels in the formative callus, both of the periosteum and of the medullary canal; many of the loops are ectasic. Cartilage cells are abundant and osteoblasts have formed in the new periosteum. The point of destruction of the old periosteum is replaced by layers of cartilage cells. Here is first seen in the series the process described by Billroth—namely, the absorption of the bone about the Haversian canals, and a granular amorphous deposit on the line of their vessels. These changes are confined principally to the borders of the shaft beneath the new periosteal development; the vessels in the central portion of the old bone have undergone no change.

The separated edges of the fractured bone have a granular appearance, and are cemented by a protoplasmic mass, which reveals no cellular development, even when magnified to eight hundred diameters.

FOURTEENTH DAY.

In this radius which was simply fissured, the periosteal development is reduced to the minimum, while the finely granular material filling the fissure, the edges of which have undergone distinct absorptive changes, is more clearly nuclear and highly refractive. The Haversian canals are being rejoined through the deposited material. The injection failed to enter the finer vessels.

SIXTEENTH DAY.

The specimen from the sixteenth day shows especially well the injection of the vessels in the developed callus, which is, in a great measure, ossific. The place of the old destroyed periosteum is refilled with cartilage cells,

NINETEENTH DAY.

The specimen taken at the nineteenth day was mounted in glycerine and colored with carmine, and it shows yet more interesting changes than any of the previous ones. The displacement of the fragments is very considerable, and the callus is in proportion developed. The changes in the shaft of the old bone are less marked, and are chiefly confined to its periosteal surface. The Haversian canals are very little altered; the medulla, although the bone is displaced by half its diameter, has taken equally with the periosteum an active share in the reparative processes.

TWENTIETH DAY.

The displacement in the specimens of the twentieth day was very slight, and the process of repair is much more advanced than in the preceding one.

TWENTY-FOURTH DAY.

The specimens of the twenty-fourth day show complete and truly ossific union. The Haversian canals are re-established throughout the divided portion, and much of the redundant exudation has been re-absorbed.

From these microscopic studies we may make several deductions:

1. As to the existence of the exudation from the parts surrounding the fracture, which as early as the sixth or eighth day is well developed and covered with a smooth, shining surface—the new periosteum,

2. The destruction of the old periosteum at the point of injury,

3. It seems to me to be demonstrated that the exuded elements have an individuality peculiar to themselves; that this protoplasmic or germinal material is placed in such relations to the new and very vascular periosteum, that osteo-

blastic cells are rapidly evolved, and arrange themselves in relation to each other and the previously formed material in accord with a fixed law. Professor Ercolani arrived at a somewhat similar deduction when he said "that this new periosteum which is formed impresses its osteo-genetic action on the exuded cellular elements, and that it is by this that they are transformed into bone."

Two conditions are indispensable for the development of the external callus and its ossific function. First, there should be an exudation of plastic or germinal material; and second, that this should be covered by, or in close relation with, a newly developed periosteum, and either of these conditions failing, the repair processes are not perfected. This condition of the transformation of the soft neoplasm into osseous substance shows us, as hinted when describing fissures of bone, why the consolidation of fissures does not take place, and this, in turn, teaches the importance of recognizing these two fundamental factors in the formation of the callus.

I call attention to two specimens from the buffalo as illustrating in a marked degree these deductions. The first is the spinous process of a vertebra, showing gun-shot injury. The bullet was flattened against the bone, and is retained in its position by outgrowing spicula of new bone. To the very extremity of the process, twelve inches in length, the bone is slightly roughened, showing that a periostitis supervened the injury, but accompanied by a very limited exudation of neoplastic elements. The second is a compound, comminuted gunshot fracture of the scapula near its neck from the same animal. The fragments are very firmly united by an immense osteo-plastic new growth, increasing the weight of the bone perhaps one-third. Irritated periosteum and neoplastic material were both found in ample facturage for the new development.

The consolidation of fissures does not take place, because the exudation is less and the overlying periosteum is injured in such a way as to lose its osteo-genetic function, and when after a time it returns to its normal state, as shown in the examination of the various specimens referred to, either the exuded elements have disappeared, usually re-absorbed, or have become too old to feel the ossifying action of the periosteum. As stated, when discussing the development of bone, the normal function of the healthy periosteum is to supply the nutritive elements necessary to keep the bone in a sound condition ; otherwise the bones could not preserve their symmetry and their development would have no definite limits.

In fractures with overlapping or marked displacement, we have seen that the extremities take no active part in the restorative process, but are united by an ossific mass deposited between the sides facing each other, a transverse section showing a direct continuity of substance. This osteo-plastic development must be assigned to the periosteum, but in a manner quite different from that formerly ascribed to it.

We have noticed already in the ossifying callus, as early as the fifteenth day in the specimens from the rabbit, that the union between the old shaft and the new bone had become intimate, and that the new osseous substance was covered by new periosteum in direct continuity with that of the shaft at a distance from the fracture. When the exudation which is given out from the superficies of the two fragments meet, they blend, and, covered with the newly-developed periosteum, place the callus in a condition for ossification, and the union by new bone firmly joined is the result.

The exudation of soft neoplasm which is necessary for the formation of the callus, is of great importance here for determining more actively the irritation of the periosteum in the opposing sides of the fragments ; otherwise there would be no reason why the external surface should preserve its normal condition, and the new osseous substance form only at the place where the fragments face each other, and between which is necessarily found the exudation in greater abundance.

In compound fractures, these factors which enter into the process of repair vary with the condition of the injury and the disposition of the fragments. In spongy bones, where the displacement is generally inconsiderable, the most important share in the restorative process is due to the elements that compose the medullary or spongy substance, and more rarely do we find an imperfectly formed callus. A beautiful specimen illustrative of this is from the Warren Museum, and exhibits both modes of union. The patient sustained a fall three years before death, due indirectly to the injury. The anterior portion of the body of the twelfth vertebra is in large measure wanting and separated from the eleventh by an interosseous space, but in the posterior part the osseous substance of the vertebræ is not only in contact, but very firmly united by a bridge of dense bone. There is a true ossific union externally between the portions of the fractured vertebra with a sub-periosteal osteoplastic layer of new bone, and upon the right side the folding together of the external plates is distinctly marked. The internal callus is owing entirely to a transformation of the elements composing the medulla. The study of an ununited fracture—the humerus, for example—is instructive in this connection. Here, owing to motion, the medulla in the cancellated structure of the bones ossifies without union, and after a time, by the perverted action of a process intended to re-establish the continuity of a part, actually defeats it; for the bone-forming elements have gone on to a high development of ossific deposit, locking up their germinal material and separating the cancellated extremities by a firm bony deposit. This must be surgically removed to bring the medullary elements in apposition before it can become an active factor of repair.

Summing up the various factors which we find enter so widely into the modes of repair in fractures, we conclude that the germinal material which is effused in the vicinity of a fracture must be placed under certain defined conditions to secure therefrom an ossific development.

From Ollier's many and varied experiments upon the periosteum, he found that to produce true ossification in transplanted periosteum, this must not only be revitalized by its connection of vascular character in its new relations, but must pour out, or furnish, an exudation of germinal matter *sui generis*. This exudation occurs only when the periosteum is irritated, not destroyed, and then there takes place a true ossific deposit, otherwise it does not produce bone.

The process of consolidation in fractured bones is not uniform, but varies according to the quality and shape of the bones and the kind of fracture, as well as to the relations which are established between the fragments.

These different elements, as we have shown, unite in many ways to produce the final result of consolidation. Although we have demonstrated that, strictly speaking, there is no primary union in bone as in other tissues, we may safely draw the conclusion from our studies, which happily has been reached from the experimental standpoint of practice, that by careful and complete adaptation of the fractured parts we place the various factors of repair in such a relation that they most readily combine to aid in the restoration of the part, and, by retaining them undisturbed a certain period, we assist in producing a more certain and satisfactory result.