Smyth, (A.W.)

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COLLATERAL CIRCULATION IN ANEURISM.

REPORT

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IN A CASE OF

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NEW AND SUCCESSFUL OPERATIONS

IN RIGHT SUBCLAVIAN ANEURISM,

WITH ORIGINAL VIEWS

ON THE IMPORTANCE OF THE COLLATERAL CIRCULATION.

The patient, William Banks, upon whom were performed the operations mentioned in this report and forming the subject of this article, was admitted into the CHARITY HOSPITAL, New Orleans, on the 9th of May, 1864, with aneurism of the right subclavian artery. He was a native of New Orleans, aged thirty-two years, a mulatto, rather below the medium height and weight, and had been employed as steward on board of a steamship.

The tumor had reached the size of a small orange, had existed four months, and was situated in the posterior inferior triangle of the neck. It pulsated strongly, and was very painful. The man had strained his arm severely in the month of February, in efforts to save himself from drowning in a collision at sea. This over-exertion was no doubt the cause of the aneurism.

On the 15th of May, with the assistance of Doctors Holliday and Boyer, and Surgeons Bacon and Orton of the United States Army, a ligature was placed on the innominate artery, a quarter of an inch below its bifurcation; and at the suggestion of Dr. D. L. Rogers, of New York, who was present, a ligature was also tied on the carotid artery, an inch above its origin.

The temperature of the arm became increased; but, except slight fever, no other disturbance was noticed.

In forty-eight hours slight pulsation was discovered at the wrist.

On the 28th of May, the ligature came away from the carotid artery; and on the 29th, fourteen days after the operation, a severe hemorrhage occurred, causing syncope, and ceasing of itself. About sixteen ounces of blood was supposed to have been lost.

Slight hemorrhage took place on the two following days: and on the 1st of June, I filled the wound with fine shot, (No. 9), covered the shot with some lint, and, as the patient was very quiet and not disposed to move. I placed a small paper weight on the lint to increase the pressure.

On the same day, after the introduction of the shot, the ligature, on slight pulling, came away from the innominate artery. I was desirous of having it away, thinking that the shot by its pressure might the sooner bring about occlusion of the artery.

On the 17th of June a portion of the shot was taken out. Hemorrhage returned a few hours afterwards, when the shot was immediately replaced.

Slight bleeding, however, occurred at intervals of two and fifteen days; and on the night of July 5th, a terrific hemorrhage took place, exceeding in quantity the first, on the 29th of May. The bleeding ceased as in the first instance, from syncope.

I had come to the conclusion at this time that the vertebral branch of the subclavian was carrying on the collateral circulation. Prof. Erichsen in his work, *The Science and Art of Surgery*, says: "I think that the presence of a collateral branch in close proximity to the distal side of the ligature, more especially if it be one that serves to carry on the anastomosing circulation, will be found to have a decided tendency in preventing the occlusion of the distal end of the artery, and will thus act in favoring the occurrence of secondary hemorrhage." The peculiar character of the hemorrhage, the sudden syncope and arrest of the bleeding, and its repeated occurrence in the fatal cases of this operation, could all be accounted for by this retrograde current through the vertebral,—the hemorrhage coming directly from the brain.

Having satisfied myself by repeated attempts on the subject, that the vertebral artery could be ligated just before it enters the foramen in the transverse process of the sixth cervical vertebra, through an incision made along the outer edge of the sterno-mastoid muscle, and the aneurism having diminished enough in size to permit of this operation, I determined to try it; and on July 8th, with the assistance of Dr. P. C. Boyer, a ligature was placed on the vertebral artery.

The circulation in the arm was very much diminished by this operation, all pulsation ceased, coldness and œdema supervened, and for several days the safety of the arm was endangered.

On July 9th all the shot was removed from the wound with a pair of curved dressing forceps, and weighed two ounces and a half. The shot had remained in the wound thirty-eight days.

No further hemorrhage took place. The ligature came away from the vertebral artery on the tenth day, and on the 15th of September the wounds had healed, and the patient was considered cured. Some paralysis of the extensor muscles of the fingers of the right hand remained, the consequence of pressure from the weight of the arm on the musculo-spiral nerve during the long confinement to bed.

After the patient left the Hospital he resumed his employment of steamboating, and for this reason came only occasionally under observation.

He was exhibited at a meeting of the American Medical Association in New Orleans, on the 6th of May, 1869, and then no vestige of the aneurism remained. Naturally enough, no great interest was manifested in the case. There was nothing to be seen but the scars left from the operations. The use of shot to prevent hemorrhage and the ligation of the vertebral artery were original procedures in surgery. The conclusion to which the members came, that the operations never had been performed at all, was perhaps not to be wondered at. The operator was unknown. I stated in the meeting that the ligation of the vertebral artery, to arrest collateral secondary hemorrhage from the distal end of the ligated innominate artery, was a procedure entirely new in surgery; but this only made the matter worse to those who had had no experience upon the point, and had bestowed no attention upon it, and there-

fore could not possibly know anything about it. It was only the more incomprehensible to them. The surgeons of New Orleans believed it, for the character of the gentlemen present at the operation was known to them. The late Prof. Valentine Mott received a minute account of the operation from his friend Doctor Rogers, and gave full credit to it. Prof. Erichsen noticed the case in his work on surgery; and I received a letter from Sir William Fergusson, acknowledging it. The tying of the vertebral artery was to these gentlemen a satisfactory explanation of the success of the operation.

Shortly after this time, Banks took up his residence in Galveston, Texas, and was lost sight of for some years. He wrote me in June, 1874, that the tumor had returned to his neck and was causing him some pain. I requested him to come to New Orleans at once, but he did not come until September, when I was surprised to find that the aneurism was considerably larger than at the time of the original operation. It did not pain him much, no doubt from its slow growth. He said that he had noticed that the tumor had been returning for about a year. Pulsation was perceptible, but not strong. The fingers applied over the tumor were seen to be elevated with each arterial pulsation. The tumor was tense, globular in shape, with distinct boundary. It occupied the original site, filling the posterior inferior triangle of the neck.

Repeated careful examinations principally directed to the cardiac side of the tumor failed to reveal any pulsating artery communicating with it; and believing that a single branch of the subclavian was carrying on the collateral circulation, and that this branch was on the cardiac side, I considered the internal mammary the one most likely to be carrying the retrograde current, from its free anastomosis with the deep epigastric. It might possibly have been the superior intercostal, but this I could not reach. I therefore determined to ligate the internal mammary artery, and on October 5th the patient was again admitted into the Hospital, and the same day, with the assistance of Drs. Boyer and Souchon, a ligature was tied on the artery in the third intercostal space.

The artery was small, and when exposed with the ligature around it, no pulsation could be detected in either direction.

The patient recovered quickly from this operation, and left the Hospital on the 10th of November. He complained a good deal of pain, caused by cutting the intercostal muscles, and said the operation was the most painful he had undergone. Some improvement was thought to have taken place in the tumor. This, I think, was entirely owing to rest. A small abscess formed under the clavicle; this was punctured with a trocar, and the contents were drawn off twice; an incision was made into it, and a tent put in, which caused it to disappear.

He now insisted on returning to Galveston, declaring that he was easier and believed he would get well. He did not come back until March 29th, 1875, and then it was the return of the abscess that induced him to do so. He would not let it be opened in Galveston, and it had become quite large and prominent under the clavicle. No change seemingly had taken place in the aneurism. I drew off the contents of the abscess with a fine trocar. The pus was mixed with blood of a dark color. He promised to return the next day, but did not do so. The day after, I was informed he was much worse, and I ordered him to be brought back to the Hospital. On his admission I found

that the aneurism had ruptured into the cavity of the abscess, and had become diffused.

On the following day the arm was swollen and painful, with great tension about the shoulder, extending below the clavicle. I determined on one more effort; and with the approval and assistance of Prof. T. G. Richardson of the University of Louisiana, the patient having been placed under chloroform, I laid open the sac of the aneurism by a free and deep incision; scooped out the clots of blood as quickly as possible, hoping to be able to reach the mouth of the vessel supplying the sac; but not knowing the direction of the current, and the hemorrhage being very great, I was compelled to give up the search, and to arrest the bleeding by stuffing the sac with lint. The patient became pulseless for a time, but reacted. Some hemorrhage, not to any great extent, took place two days afterwards; but he rapidly failed in strength and spirits, and soon betraying utter discouragement and prostration, finally died on the 6th of April, 1875, within thirty-three days of eleven years after his original entrance into the Hospital.

A few hours after death about half a gallon of solution of chloride of zinc was injected into the right femoral artery; and on the following day, the lint having been removed from the sac of the aneurism, the opening was carefully stitched up, and a compress of lint secured by a bandage placed over it. A quantity of melted cacao butter, colored with carmine, was now injected into the same artery, enough to well distend the whole arterial system. Two days afterwards the body was given to Dr. Edmond Souchon, Demonstrator of Anatomy, University of Louisiana, who kindly undertook the dissection, and furnished me with the following account of the autopsy :—

"The body, not at all emaciated, was in a good state of preservation, with rather too much adipose tissue for a clean dissection; and the arteries were all apparently well distended by the injected material. No perceptible disproportion existed between the lateral halves of the body. The right arm was as muscular as the left.

"Upon exposing and clearing the parts at the root of the neck, and opening the thorax, the arch of the aorta, well injected, was found to be perfectly normal. The innominate artery was injected to the point of ligation, less than an inch from its origin, where it suddenly became reduced to a bundle of tough fibrous tissue, in which could be traced the origin of the common carotid and subclavian arteries. The carotid arising from this fibrous tissue was occluded, and continued so up to the bifurcation, growing larger as it approached this point. It was cut into, and no evidence of channel could be found. The fork of the carotid was well distended with the injection. The external carotid and all its branches were also well filled, and so was the internal carotid.

"The subclavian was impervious from its origin to within a fourth of an inch of the thyroid axis. The thyroid axis and its branches were all pervious and seemed not above the ordinary size. They were not well distended by the injected material. The subclavian from the thyroid axis to the aneurismal sac, into which it opened, was rather under the ordinary size.

"The vertebral artery originated from the subclavian as a white fibrous cord of small size, which became reduced at the point of ligation to a membranous tissue; from this point up, it increased in size and became pervious at the fourth cervical vertebra. It continued of small size into the cavity of the skull, where it was smaller than its fellow of the opposite side by at least one-third. The basilar artery was of ordinary size. The posterior communicating arteries were larger than usual, and the anterior cerebrals were freely connected by three short and large anterior communicating arteries.

"The arteries in the brain were all well injected.

"The internal mammary artery was slightly distended from its origin down to the first intercostal space. From this point it became impervious to some distance beyond the point of ligation, where it again became pervious, but of small size. The right epigastric was not any larger than the left.

"The superior intercostal was well distended with the injection, and seemed to be somewhat above the ordinary size; no anastomosing branches from it could be found communicating with the *princeps cervicis* behind. The *princeps cervicis* itself presented nothing noticeable.

"On continuing the dissection to the distal side of the sac, the first artery that attracted attention was the subscapular, with its branches to the great dorsal and great serrate muscles.

"These branches were numerous, were well distended by the injection, were as large as crow quills, and very tortuous in their course downwards. Seven of these branches communicated directly with a similar number of perforating branches from the aortic intercostals. These branches ran into each other, of full size, without the interposition of any plexus. The *dorsalis scapulæ* and the other branches of the subscapular and axillary arteries were not very well distended. They were traced far enough to show that there were no anastomoses of any consequence, either with the posterior or superior scapular arteries. The trunk of the subscapular was not well distended, and seemed not to be above the natural size. The axillary artery below the origin of the subscapular was better distended, and ran as usual into the humeral, which was well injected. This artery divided, about the junction of the upper with the middle third of the arm, into two branches which ran down along and under the median nerve to the elbow, one forming the radial and the other the ulnar artery. The profunda was exposed and presented nothing remarkable.

"The upper portion of the axillary, extending from the origin of the subscapular to the aneurismal sac, was not well distended, and seemed to be rather under than over the ordinary calibre. It was thoroughly pervious, as shown by passing a probe into it from the sac. It opened into the bottom of the sac by an oval round-edged opening, apparently not quite as large as the size of the artery. The distance between this opening in the sac and that of the subclavian on the cardiac side was about an inch. The ruptured and everted artery, with its internal coat quite distinct, extended along this distance on the bottom of the sac, recognized by its yellowish color and smooth surface. It was firmly attached to the deep parts. This internal coat of the artery did not extend upwards on the inner surface of the sac. The subclavian artery opened into the sac about a quarter of an inch from the origin of the superior intercostal artery.

"The base of the aneurism occupied the whole of the posterior triangle of the neck, encroaching upon the surrounding regions, pressing against the *trapezius* muscle behind and the sternomastoid on the inner side. In front the tumor had caused absorption of the greater portion of the clavicle—bending this bone outwards. The roof or superficial covering of the sac had been opened during life.

"From the large size of the anastomotic branches of the subscapular and the perforating branches of the aortic intercostals, it is evident that the blood had circulated in this way,—from the aortic intercostals up through the subscapular into the upper portion of the axillary, and into the aneurism,—supplying it by a retrograde current: and from the absence of anastomotic communications with the branches of the subclavian on the cardiac side of the aneurism, and from their comparatively small size, these arteries evidently carried on the retrograde circulation from the aneurism through the subclavian artery." *

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* In illustration of important points in this case, Dr. J. J. Castellanos, Lecturer on Principles of Surgery in the Charity Hospital School of Medicine, very kindly made drawings of the arteries in the base of the brain, and in the neck, with the anastomosing arteries communicating with the aneurism. The change in the direction of the right vertebral artery is prominent among these. I should like to have published the drawings with this report, but could scarcely do it satisfactorily here in New Orleans.

The anatomical preparation preserved from the case remains in the care of Dr. Souchon.

This report of Dr. Souchon's was written two years ago, and might have been published at that time. I made some delay, which may have appeared longer than was absolutely necessary, in order to enable me to give such explanations as might occur from a full and careful consideration and study of the case.

If I am correct, however, in the conclusions at which I have arrived, and which I am now prepared to state, the time taken will not, I think, be pronounced wholly lost.

The subject of aneurism is very different to me now from what it had been. The rationale of the cure of the disease, and the action of the various methods adopted to bring about a cure, are more comprehensible to me. In fact, although I had cured many aneurisms, I never knew exactly until now how they were effected. I have learned more from failure than from success, and better understand much that I had read and seen in the past. Before entering upon this subject, however, I think it of importance to give some particulars of the case not yet stated, or not as fully stated, as the reader may desire.

The exact time of the return of the aneurism is uncertain. Banks stated on his coming to New Orleans in September, 1874, that the tumor had commenced returning about a year previous to that time. Some swelling and pulsation had existed, however, even before this returning was acknowledged; for Prof. Paul F. Eve, of Nashville, Tenn., called my attention to a notice of an examination of Banks previously made in Galveston by a Surgeon of the United States Army, and mentioned in a report to the Surgeon-General. I cannot now turn to this report, but it was of much earlier date than the time given by Banks as that of the returning of the aneurism. The writer stated that slight pulsation existed in the sac of the aneurism, which, however, he did not then consider of any immediate import.

It may appear strange to the reader that the supply of blood to the aneurism through the subscapular artery was not discovered during life; but there is an explanation for this. The patient, during the time of his recovery from ligation of the internal mammary artery, was examined by many professional gentlemen,—by all the leading surgeons of New Orleans, and by other visitors, among whom I may mention Dr. Robert McDonnell, of Dublin, then present in our city. I consider that the frequent examinations during these visits caused the abscess that indirectly led to his death. Yet none of those who examined him suspected the source of supply.

From the time the vertebral artery was tied on July 8th, 1864, no pulsation ever reappeared in either the axillary or the brachial artery. They seemed to be occluded; and yet slight pulsation existed at the wrist, in the continuations of these arteries. Compressing them to arrest the pulsation at the wrist was never tried; and the total absence of pulsation in the lower end of the axillary and in the brachial arteries, created a very strong impression that the supply of blood did not come in this distal direction. I think it probable that preconceived correct opinions on the course of the circulation were sometimes changed after an examination.

The circulation of blood to the arm was very peculiar. The subscapular, from the direction of its origin, ran up in a nearly straight course to the aneurism; and the retrograde current through it, during the heart's contrac-

tion, went into the sac. Immediately afterwards, a direct current from the aneurism returned through the axillary and brachial, supplying the arm, but without any perceptible pulsation in these arteries. The supply, however, was abundant; for the right arm was as strong and muscular as the left. That portion of the axillary artery extending from the origin of the subscapular to the aneurism was carrying a double current, that is, a to and fro current. It may be better understood by saying that a systolic retrograde current to the aneurism, and a diastolic direct current to the arm, circulated through it.

I noticed during the dissection, that the elevation of the arm to a right angle with the body changed the direction of the trunk of the subscapular artery and would have reversed this circulation. With the arm elevated, the retrograde current from the subscapular would have gone directly to the arm, and a return retrograde current would have supplied the aneurism. This simple experiment would not only have revealed the source of the circulation; but would also have shown an easy way to lessen the circulation in the aneurism.

It is stated in Dr. Souchon's report that several arteries were not well distended by the injected material; and it is well, in order to prevent any wrong conjectures being made from this condition of the arteries, to explain that the injection was forced out by the compress and bandage applied over the opening in the sac. The arteries were well distended at the time of the injection, but the pressure of the bandage afterwards, while the material remained fluid, pressed some of it out. This will make it clear why the continuations of some arteries were well injected and their trunks not.

The autopsy shows nothing very remarkable except the peculiar circulation which reproduced the aneurism as mentioned in the report.

The aneurism was reformed on a retrograde current, circulating towards the heart; and I know of no previous case in which an aneurism was ever reproduced in this way.

In the application of a ligature for the cure of aneurism, we always endeavor, if possible, to throw the collateral circulation beyond the tumor; and if successful in this a cure almost always results. It did not result in a cure, however, in the present case; and to understand fully the reasons for this exception, it becomes necessary to take into consideration the action of the collateral circulation in the cure of aneurism. This has never yet been done; but I am satisfied it is a most important agent, not alone in carrying on the circulation after the aneurism is cured, but in actually bringing the cure about.

It will aid us very much in this undertaking to begin by considering what a collateral circulation is,—how it is carried on,—and the conditions which must accompany its establishment.

A collateral circulation is a circulation around an obstruction to the direct current of blood through an artery. More accurately defined, it is a retrograde circulation through a branch, from its anastomotic communications, into an artery, beyond an obstruction to the direct current through that artery.

The collateral circulation is always carried on through a single branch into an artery beyond an obstruction to the direct current through it; and

but a single branch carries on the retrograde circulation into an artery on the distal side of an aneurism after it is cured. It was my belief in this fact that induced me to tie the internal mammary artery; and the *post mortem* shows that I was right in theory, but that I should have ligated the subscapular instead of the internal mammary.

When a collateral circulation takes place in consequence of an obstruction to the direct circulation in an artery, the direct current must cease at the point of obstruction, the instant the collateral circulation becomes established. The direct circulation impinges on the obstruction on the proximal side, and the collateral circulation impinges on it from the distal side.

To those who have hitherto believed that a collateral circulation could take place into the distal end of a ligated artery, through a number of branches, that a collateral circulation could become gradually established during the increase of an aneurism, and that a direct and a collateral circulation could circulate together in an artery, the assertions just made, with regard to the collateral circulation, will certainly be new, if not startling. It is only necessary, however, to take a plan or sketch of the arteries and trace upon it the collateral circulation coming in from different branches, with the direct circulation at the same time going on in the same artery, to see the utter impossibility of any such circulation as that generally believed in ever taking place. Opposing currents cannot circulate in the same artery without interfering with each other: one must arrest the other.

The action of the collateral circulation in bringing about a cure of aneurism may be well illustrated by reference to cases of occasional spontaneous cure.

From obvious physical laws, the circulation of blood is obstructed in an artery dilated into the form of an aneurism. The obstruction is greater from a large aneurism than from a smaller one, and a weak current is more obstructed by the aneurism than a stronger one. When the obstruction, either from increase in the size of the aneurism or from diminution in the force of the current, or from both causes combined, reduces the force of the circulation in the artery and its branches, on the distal side of the aneurism, to a certain extent or degree below the force of the general circulation, a retrograde collateral circulation becomes established, through one of the branches on the distal side of the aneurism. The establishment of the collateral circulation on the distal side has the effect of arresting the obstructed direct circulation through the aneurism, and the cure of the aneurism commences from this point.

Pulsation may go on in the tumor for some time after the circulation through it ceases. It may even be quite strong, owing to the combined direct force of the circulation on the cardiac side, with the indirect force on the distal side. We know that pulsation in an aneurism, for a time, is not evidence of circulation through it: any more than pulsation up to the point of ligation on a continuous artery is evidence of circulation through this artery; and we are acquainted with the pulsation produced by the collateral circulation. It is frequently noticed coming on shortly after ligation on the cardiac side of an aneurism and continuing for two or three days longer.

The arrest of the circulation in an aneurism by the establishment of a collateral circulation on its distal side, when the arrest of circulation is not

otherwise produced, either by total obstruction to the circulation in the aneurism, or by the application of the ligature either on the cardiac or on the distal side, close to the aneurism, will readily explain to us the way in which compression brings about a cure. Compression lessens the force of the circulation in the artery to the aneurism—reducing the circulation in the artery on the distal side of the aneurism to the condition required, as already stated, for the establishment of a collateral circulation.

Compression made on the aneurism or on the artery on its distal side, if effective, must act in the same way as when made on the artery on the cardiac side of the aneurism.

It is manifest that compression is a very efficient means of establishing a collateral circulation; and that the lessening of the force of the general circulation is not; for the collateral circulation must derive its force from the general circulation, and the stronger the force of the collateral current, the more readily can it become established, and the stronger direct current is it capable of arresting.

The cure of aneurism by the use of the ligature brings us to the consideration of our present case. When a ligature is applied close to the cardiac side of an aneurism, arresting all circulation through it, the process of cure is of the simplest kind. A collateral circulation is then established on the distal side with no direct current to oppose it. But when a ligature is applied at a distance from the cardiac side of the aneurism, with branches intervening between it and the aneurism, this process of cure becomes complicated. The collateral circulation is then sometimes established on the cardiac side of the aneurism. This was the case in Banks, after the first operation of ligating the innominate and common carotid arteries. The collateral circulation was established through the vertebral artery.

The establishment of the collateral circulation on the cardiac side of the aneurism follows ligation of the external iliac artery for aneurism below the profunda, and may occur from the application of the ligature at some distance from any aneurism, provided a branch or branches of some size intervene. When a cure takes place after the establishment of the collateral circulation on the cardiac side of the aneurism, it takes place more slowly than when the collateral circulation is established on the distal side, and the cure is brought about by a change of the collateral circulation from the cardiac to the distal side of the aneurism.

Occasionally the collateral circulation on the cardiac side of an aneurism reproduces it. In a case of femoral aneurism treated in this Hospital a few years ago, the collateral circulation, from occlusion of the iliac by digital compression, continued to increase the aneurism more rapidly than the direct current. I attributed this at the time to absence of resilience in the tumor during the heart's diastole. This, I considered, left no opportunity for circulation within the boundaries of the sac.

When a collateral circulation becomes established on the cardiac side of an aneurism, after ligation on the cardiac side, the ligature may be said to act in the same way as compression. It does not cut off all the circulation. It lessens it by substituting a collateral current in place of the direct one; and in the event of a cure following, a collateral circulation becomes estab-

lished on the distal side, opposing and arresting the collateral circulation on the cardiac side.

In some instances, this transfer of the collateral circulation from the cardiac to the distal side must be interfered with by pressure of the tumor.

In Banks, the collateral circulation established through the vertebral artery on the cardiac side of the aneurism was changed to the distal side by ligation of this artery; and as other branches besides the vertebral existed between the ligature on the cardiac side and the aneurism, the collateral circulation on the distal side established a current through the aneurism to these branches.

If secondary hemorrhage had not occurred, necessitating the tying of the vertebral artery, and if the collateral circulation had changed from the cardiac to the distal side of the aneurism, with the vertebral open, the collateral circulation on the distal side could not have passed to the branches on the cardiac side of the aneurism; for the current from the vertebral would have supplied these branches and opposed the retrograde current through the aneurism.

If the innominate artery had been successfully ligated without the vertebral having been tied, it is legitimate to suppose that the retrograde current from the vertebral might have supplied the other branches of the subclavian on the cardiac side of the aneurism, and that a retrograde current through the subscapular would have supplied the axillary and its other branches beyond the aneurism. This would have been an instance of two branches carrying a retrograde current into the distal end of a ligated artery. It will be perceived, however, that there existed two obstructions to the direct circulation to account for this.

The circulation in Banks was indeed very peculiar. It was produced by two operations:—first, by the ligation of the main artery going to an aneurism; and secondly, by the ligation some time afterwards, of a branch carrying on the collateral circulation on the cardiac side of the aneurism. If this branch had been the only one intervening between the ligature on the main artery and the aneurism, a total arrest of circulation through the aneurism would have been effected; but three other branches, the internal mammary, the thyroid axis, and the superior intercostal, also intervened; and the collateral circulation established on the distal side of the aneurism, by the ligation of the branch carrying on the collateral circulation on the cardiac side, passed through the aneurism to the branches on its cardiac side.

It is probably safe to say that no such circulation ever existed before, and it could have been produced in no other way than by the two operations mentioned.

We have seen that a collateral circulation can be established on the distal side of an obstruction in an artery, opposing a collateral circulation on its proximal side. Now, if we understand the circulation as it existed in Banks, we can see that the collateral circulation, established on the distal side of the aneurism, could have been arrested only by the establishment of a collateral circulation on its cardiac side; and the important question arises, can such a collateral circulation be established? Can a collateral circulation be set up on the cardiac side of an obstruction to the circulation in an artery, after a

collateral circulation has been established on its distal side? In reply to this question, I answer "No!"

For years, a weak, indirect, collateral current circulated through an aneurism, to branches on its cardiac side. These branches,—the internal mammary, the thyroid axis, and the superior intercostal,—were, from their anastomotic communications, as capable of carrying on a retrograde circulation, as the branch that supplied them from the distal side of the aneurism; and it is evident that the force of a collateral circulation through an aneurism cannot equal the force of a collateral circulation without the obstruction of the aneurism; so that the distal collateral circulation did not, by its force of current, oppose the establishment of a collateral circulation on the cardiac side. The conditions, as far as we can see, were all favorable for the establishment of a collateral circulation on the cardiac side of the aneurism,—necessary to bring about its cure. It did not, however, take place. Such an event would have been contrary to the law that the collateral circulation is established on the distal side of an obstruction to the direct circulation.

I have been frequently asked why I did not ligate the axillary artery above the subscapular; and Dr. Souchon originally closed his report by saying that this ought to have been done. I have omitted the suggestion, first, because it was too late, and secondly, because it was made without the reflection, that this operation would certainly have been followed by secondary hemorrhage. It is precisely the operation to which Prof. Erichsen's remarks already quoted apply. The only safe ligation would have been that of the subscapular artery,—a very different operation from the other. This might have thrown the collateral circulation again on the cardiac side of the aneurism; but if my present reasoning is correct, the aneurism could have been cured only by a return of the collateral circulation again to the distal side. With the subscapular tied, this might have been impossible; and I now see that it was not so easy a matter as some suppose, to have cured the recurrent aneurism in Banks, by the ligation of any artery.

Consulting brevity, as far as consistent with clearness, I will state, in the form of propositions, the conclusions to which, from consideration of the present case, I have been led, concerning the cure of aneurism, and the action of the collateral circulation in bringing it about. Conditions, applying only to the exceptional case of Banks, are enclosed in brackets:—

1.

The complete cure of aneurism, that is, solidification and absorption of the tumor, with the occlusion of that portion of the artery involved in the aneurism, always results from the total arrest of the circulation of blood in the aneurism.

2.

When a cure of aneurism follows from procedures lessening the force of the direct circulation to the aneurism, or from increasing the obstruction to the circulation in the aneurism, or from obstructing the circulation in the artery or arteries on the distal side, the total arrest of the circulation in the aneurism, required to effect a cure, is caused by the establishment of a collateral circulation on the distal side of the aneurism.

3.

A collateral circulation is established on the distal side of an aneurism, when the force of the circulation in the distal continuation of the artery involved in the aneurism becomes reduced to a certain degree below the force of the circulation in its anastomosing arteries.

4.

The collateral circulation on the distal side of an aneurism opposes the direct circulation through the aneurism. The retrograde collateral current must arrest the obstructed direct current. [*The collateral circulation under extraordinary circumstances may establish a retrograde current through the aneurism to the artery and its branches on the cardiac side, if this artery is occluded on the cardiac side of the branches.*]

5.

The collateral circulation is always carried into the distal continuation of an obstructed or occluded artery, through a single branch. A careful consideration of the currents in the circulation will show a necessity for one branch alone carrying the retrograde current, and a necessity for some action controlling this and regulating the circulation in the communicating or anastomosing branches between arteries. Aneurisms are not the only accidents to the circulation requiring the establishment of a collateral circulation. It is reasonable to suppose that during health temporary obstruction to the circulation in an artery gives rise to a collateral circulation,—ceasing on removal of the obstruction and restoration of the direct current.

6.

The collateral circulation consequent upon obstruction to the direct circulation in an aneurism, and upon obstruction to the circulation in the artery or arteries on the distal side, is always established on this side. In the use of compression or ligation on the cardiac side, at some distance from the aneurism, causing a greater obstruction to the direct circulation than that arising from the aneurism, the collateral circulation is occasionally established through a branch on the cardiac side of the aneurism, but on the distal side of the greater obstruction. In the event of a complete cure following the establishment of this proximal collateral circulation, the cure is brought about by the subsequent establishment of a distal collateral circulation which arrests the proximal collateral current through the aneurism.

7.

In all aneurisms, except sacculated aneurisms, involving a portion of the wall of an artery, or aneurisms through which the circulation is totally arrested by the use of the ligature, or by complete obstruction in the sac of the aneurism, the cure is owing to the establishment of a collateral circulation on the distal side of the aneurism, which arrests the direct circulation in the aneurism.

8.

When the collateral circulation becomes permanently established on the distal side of an aneurism, its cure is certain to follow, unless hemorrhage, rupture, or suppuration of the sac, should ensue, [*or a retrograde current through the aneurism from the collateral circulation to the artery and its branches on the cardiac side should be established.*]

The consideration of the collateral circulation is necessary to enable us to comprehend many of the well-known facts connected with the cure of aneurism. Indeed, many of the phenomena connected with the cure are incomprehensible without a knowledge of its action. Pulsation may go on for days after the circulation has ceased, arising from the indirect collateral current alone; and often the direct and indirect currents both combine in producing it. Spontaneous cure sometimes takes place, and compression of variable degree and duration of time effects a cure. Frequently, some time after the compression has been withdrawn, a spontaneous cure follows.

The theories advanced to explain the cure of aneurism without taking into consideration the action of the collateral circulation are not well founded. It is held that a weak current of blood circulating through an aneurism forms a *coagulum*,—a deposit of fibrin in the sac, of a different kind from that left by a more active or stronger current,—and that the deposit from the weaker current is capable of totally arresting the circulation of blood through the aneurism; of solidifying and of becoming absorbed; leaving the artery permanently occluded. Our present case has proved all these theories untenable; and the *post mortem* shows that no arteries were permanently occluded except those in which the circulation was totally arrested. The aneurism was absorbed, and was reproduced by a weak current; and for ten years a weak current circulated through it, and still the aneurism was not completely cured.

It is commonly asserted that the collateral circulation is becoming established during the increase of an aneurism. I believe that during the increase of an aneurism the collateral circulation frequently arrests for short periods of time the direct circulation through the aneurism. The two circulations may be said to alternate with each other. The deposit of fibrin on the inner walls of an aneurism, taking place in separate and distinct layers, indicates the occurrence of an intermittent action in the direct current. The obstruction to the circulation in the aneurism is diminished in consequence of the deposit of a *coagulum* in the sac of the aneurism, which lessens the quantity of fluid blood contained in it, during the arrest of the direct circulation; and this enables the direct current to become again re-established—the collateral current ceasing. From the action of the collateral circulation in this way only can it be said to become gradually established. Increase in the size of an aneurism increases the obstruction to the circulation of blood through it, tending to set up a collateral circulation. When the collateral circulation becomes permanently established, it may, by increase in the number and size of the communicating or anastomosing branches to the single branch carrying it into the artery on the distal side of the aneurism, keep increasing in force and volume for an indefinite period of time.

The short communicating arteries frequently laid down in surgical works, as uniting the two ends of a ligated artery, and illustrating the manner in which the circulation is then carried on, are wholly imaginary. They can have no existence.

In conclusion, it may be asked, What have we learned from these operations, and, how can the knowledge obtained be applied in directing our efforts to greater success in the future?

We have learned that the innominate artery has been successfully ligated in a case of subclavian aneurism; and from the relation or affinity existing between like things, this extraordinary operation has been followed by an event perhaps quite unprecedented. After an interval of ten years, the one followed as a consequence of the other. An aneurism was reproduced by a retrograde collateral current of blood, circulating through it from the distal, to branches on its cardiac side. We have learned that in this strangely reversed circulation, arising from the interruption of a collateral current to the distal side of a ligated artery, the usual law governing the establishment of the collateral circulation could no longer operate towards the effecting of a cure. It has been proved that the innominate, the common carotid, the vertebral, and the internal mammary arteries could all be successfully ligated on the same patient, without curing a subclavian aneurism on their distal side. It may be claimed, however, that a cure was effected for ten years; for during that period the patient enjoyed the best health of his life. He gained twenty pounds in weight and possessed the full and complete use of all his physical and mental faculties. We have learned that ligation of the innominate and common carotid arteries, with the ligation of the vertebral to arrest secondary hemorrhage from the distal side of the ligated innominate artery, is a successful operation for the cure of subclavian aneurism, compared with the operations of the past. We have learned, I think, the reason why it is objectionable under some circumstances, when it can be avoided, to ligate a collateral branch carrying the retrograde current of blood to the distal side of a ligated artery, to arrest secondary hemorrhage from it. And we have learned something about the collateral circulation and its action in bringing about a cure of aneurism. Surely all this knowledge, derived from the successful ligation of the innominate artery, should be enough to disprove the stereotyped denunciations of this is an "unjustifiable" operation.

We have also learned from the present case that ligation of the innominate and common carotid arteries alone, without that of the vertebral, would in all probability effect a complete cure of subclavian aneurism. It seems to me the course to be adopted in the future is quite plain. We must endeavor to ligate the innominate and common carotid arteries, in some way that will prevent the occurrence of secondary hemorrhage, which alone has proved fatal to the vast majority of the patients hitherto operated upon. In this attempt, recourse to the ligation of the vertebral artery, if secondary hemorrhage should come on, makes it safe to adopt any procedure that promises a chance of success.

The discovery of a means of arresting the secondary hemorrhage from the distal side of the ligature on the innominate artery, and effecting a cure of aneurism for a period of ten years, is a long step forward from the past. Patients will not be allowed to bleed to death from this hemorrhage as they have been heretofore. The abundance of loose cellular tissue in the root of the neck makes it an unfavorable locality for trying the antiseptic ligature; still it may be worth the attempt I have thought for some time that should another case of right subclavian aneurism present itself to me, I would tie the innominate and common carotid arteries, and, making a longitudinal incision opposite the origin of the subclavian, would, through the incision, insert into this artery a round ball of lead or some lighter substance which we know to

become readily encysted, and await the result. Several sizes of shot attached to the ends of curved wires would determine the proper size to introduce, and the plug should be forced some distance into the artery. I would try this operation on the left side by tying the subclavian, making a longitudinal incision on the distal side of the ligature. I should not dread any danger from a single hemorrhage from the vertebral; and on its occurrence I would ligate this artery as I did in Banks.

I would not amputate at the shoulder joint, for several reasons. First, it is an operation to which patients do not readily consent; secondly, even if successful it cannot be more so in my opinion than that performed in the present case; and, thirdly, it is an operation from which nothing valuable can be learned, and nothing creditable ever obtained. After the experience and knowledge derived from the operations here recorded, I could not but consider it a most objectionable procedure. I prefer to take my place upon the page of surgical history among the ligators of the innominate, and with them, in our common effort, share the credit of endeavoring to accomplish a result more beneficial to our race, and more honorable to our profession.