MICROSURGERY AS AN AID TO MIDDLE CEREBRAL ARTERY ENDARTERECTOMY*

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Attempts to remove obstructions either in the form of emboli or sclerotic plaques from the human vasculature have met with notable success in recent years in the case of the aorta and vessels of the lower extremities. More recently the carotid and vertebral arteries in the neck have succumbed to the surgeon. The intracranial vessels have not been so subdued. Anyone who has attempted to open and close and to maintain patent a vessel measuring less than 3 mm. in diameter is no stranger to frustration. The purpose of this paper is to bring to your attention a technique that can be of help in relieving the feeling of inadequacy when confronted by a minute but essential vessel, which must be allowed neither to bleed nor to obstruct, and whose repair must be accomplished at some depth, often with nearly invisible suture. The technique also has promise in many other areas of vascular surgery,3–5,7,10 ureteral reconstruction,11 organ transplantation,8 and in fact in any situation in surgery when smallness of structure or desirability of finely placed sutures is present.

At the meeting of the Harvey Cushing Society in 1955 Welch12 reported the surgical removal of obstruction from the middle cerebral artery on two occasions.

One patient with an obstruction just beyond the posterior temporal branch was operated upon, and an embolus was removed 28 days following the onset of symptoms.

This patient has shown excellent neurological recovery and repeated angiography reveals patency of the ascending branches of the right middle cerebral artery, but without filling of the posterior temporal branch.

The other patient, with occlusion shortly beyond the intracranial bifurcation of the internal carotid artery, was operated upon the day of onset. An embolus was successfully recovered. She remained hemiplegic and her postoperative angiogram showed recurrent closure of the vessel in this same area.

Scheibert13 at the meeting of the Harvey Cushing Society in 1959 presented his series of 4 cases. He has added 1 case since.14 In 1 case, that of a 66-year-old male, he was able to establish patency and to maintain this for 8 months, as proven by angiography. This patient died of coronary occlusion 9 months after operation. Patency was not maintained in the other 4. So far as we are aware this is the only case in which a middle cerebral artery has been opened and closed and then remained fully patent.

Piazza and Gaist15 reported in 1960 a fascinating case of embolism of a shotgun pellet to the middle cerebral artery in a 22-year-old man. Dr. M. Milletti in Bologna operated and milked the pellet back to the internal carotid artery, then occluded the internal carotid above this point, thus preventing the pellet from again entering the middle cerebral circulation, and leaving the carotid of the opposite side to nourish both middle cerebral arteries, which it was demonstrated by angiography to do exceedingly well. This most ingenious procedure, however, cannot have wide application because

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most obstructions of the middle cerebral artery are not so freely movable, and many patients could not tolerate as easily as this 22-year-old healthy male, the loss of the internal carotid supply.

Crawford et al.² have written concerning endarterectomy, "The major limiting factor in the application of these procedures to small arteries has been lumen constriction resulting from arterial repair."

Carton et al.¹ have devised a method of attaching a patch to small vessels with a glue. Sussman and Fitch¹⁷ have suggested the intravascular use of fibrinolysin. The limitations of each method can best be learned from the words of the authors in the appended bibliography. None is truly ideal.

Our own method is but one additional attempt at circumvention of the situation to which Crawford alluded—a condition exemplified by Poiseuille's Law—the flow of fluid through a vessel is directly proportional to the fourth power of its diameter.¹⁵

One of us (JHJ) had come to the conclusion that many failures in small-vessel surgery were caused by errors in placement of sutures, and that these errors were in part ascribable to errors in human vision. An error of 1 mm. in the placement of the suture in a 2 cm. vessel is well tolerated, but in a 2 mm. or 3 mm. vessel such misplacement spells partial occlusion. We experimented with a variety of magnifying glasses and ocular loops to increase visual acuity. Each proved unsatisfactory for one or more of the following reasons: 1) Too low a magnification; 2) too short a working distance between the magnifying device and the operative field; 3) the necessity for holding the head in exactly the correct position, resulting in surgical torticollis; and 4) difficulty in changing easily from the magnified area to the general operative field.

Borrowing a leaf from the otorhinolaryngologists' book, a dissecting microscope* was taken into the laboratory as shown in Fig. 1. First experiences with the microscope may be likened to the first time that the moon is viewed through a powerful telescope. A whole new area of detail is appreciated. Previously unrecognized technical error becomes glaringly apparent.

With the aid of this instrument laboratory success has been achieved in arterial replacement of small vessels.⁶,⁹

In the operating room the microscope is covered with a sterile drape, and a sterile metal ring is fitted over the objective. The ring prevents both slippage of the drape over the lens and inadvertent contamination of the lens (Fig. 2). Depending upon the choice

* Courtesy of Mr. Erich Friedrich, Carl Zeiss, Inc., 485 Fifth Avenue, New York, N. Y. A new double binocular microscope (diploscope), allowing both the surgeon and assistant to view the operative field, is available.
of objectives and oculars a wide range of magnification can be secured. In general magnifications used are from 6 to 40 power. The 300 mm. objective gives a lens-to-subject distance of 8 inches, which has proven satisfactory for laboratory work. In the depths of a wound, as in the case of middle cerebral endarterectomy, additional distance is desirable. A 300 mm. objective, giving a 12-inch working distance, has been used. Generally a magnification of 10 or 16 is used for placing stay sutures, and preparing the field, with fine suturing carried out at 25 or 40 power. When necessary, as in machine-shop practice, dissection and placement of sutures are performed with the instrument stabilized by a "rest." At times this is a bar placed in the field, but more often is a finger of the other hand, or convenient part of the operative field.

In general our surgical instruments have required only miniaturization of the tips. We have, however, abandoned the commonly used needle holders and scissors with ringed handles. Fine motion of the fingers is essential. While this is possible with the conventional instruments if held along the shank, release of the instrument must be done with the ring handle, frequently resulting in unnecessary trauma. An entirely new line of instruments are being developed for application to middle cerebral endarterectomy.* Fig. 3 depicts the design that was proven most satisfactory for a number of these instruments. The needle holder shown is held along the shank and is locked or unlocked by simply pinching the handle.

Suture materials in general use have proven to be unsatisfactory. A #7-0 silk swaged on a fine needle was secured. While the majority of our work to date has been done with this material, it also has proved to be too traumatic for smaller structures. Recently an ultrafine suture has been developed of monofilament Nylon,† so thin that it is almost at the limit of vision. This has been swaged to a needle 6/1000 in. in diameter. To date these are handmade, but should soon become available commercially (Fig. 4).

In vessels of the dog, cat and rabbit, arterial and venous autografts and arterial homografts have been used to replace segments of femoral or carotid arteries measuring 1.4 mm. to 4 mm. in size. These replacements have measured 2.5 cm. in length. They have been followed 6 months to 1 year with a patency rate of 100 per cent. Our smallest replacement thus far has been in the femoral artery of a cat, which measured 0.8 mm. in diameter. An arteriogram taken 3 months later is reproduced in Fig. 5.

Eighteen arteries measuring on the average 3 mm. in size have been replaced by 3 mm. Teflon grafts. Of these, 17 have become occluded. It is believed the growth of new lining in these grafts narrows the lumen to below a critical point.

Twenty endarterectomies have been done in 3 mm. and 4 mm. vessels for distances of 2.0 cm. to 2.5 cm. and of these 16 have remained patent. The 4 failures occurred in 2 dogs in which bilateral infections of the wound developed. Anticoagulants were not used in these experiments except for rinsing out the graft and sites of sutures with dilute heparin solution (50 mg. in 30 cc. of saline).†

Theoretically a transverse incision will cause less narrowing of the lumen and would ordinarily seem to be the incision of choice. We favor such an incision when one is dealing with the simple extraction of an embolus, but in the case of occlusive plaques, in which it is so important that an absolutely smooth surface be maintained along the media, we employ a longitudinal incision over the entire extent of the area to be endarterectomized. This is based on poor results in a pilot study in which a miniaturized endarterectomy stripper was inserted through a transverse incision. An onlay venous autograft placed

* Specialized instruments have been developed through the courtesy of:
1) V. Mueller & Co., 320 S. Honore St., Chicago, Illinois (Mr. William Merz).
2) B. Richter, 334 E. St. Charles Road, Lombard, Illinois (Mr. B. Richter).
3) Storz Instrument Co., 4570 Audubon Ave., St. Louis, Missouri (Mr. J. Herman Bels).

† Courtesy of Mr. C. W. Norman, Ethicon, Inc., Somerville, New Jersey.
between the edges of the longitudinal incision, in order to increase luminal diameter, is an attractive possibility that remains to be evaluated experimentally in very small vessels.

In a large blood vessel infrequent sutures secure excellent hemostasis at the expense of eversion or inversion, which may be unimportant clinically. In the small vessel, however, it is extremely important to avoid inversion, eversion or bunching at the line of suture. While accurate coaptation can be accomplished with a few fine sutures, hemostasis is not satisfactory unless sutures are grouped more closely. Fig. 6 shows a 3.5 mm. artery endarterectomized 4 months previously; 58 stitches have been used to close the 2 cm. incision.

CASE REPORTS

The possibility of utilizing this method for embolectomy and endarterectomy of the middle cerebral artery occurred to one of us (RMPD) hard upon the unfortunate experience of a complication of angiography, and after consultation it was decided to attack the first favorable lesion in this manner. Shortly thereafter the first patient upon whom we wish to report was admitted to one of us (GAS).

Case 1. A 50-year-old white male executive had been in good health until 11:20 p.m. July 30, 1960, when, as he entered his car, he suddenly slumped in the front seat, ceased to speak and lost all movement of his right arm and leg. At his local hospital a lumbar puncture revealed clear fluid under normal pressure. He remained totally aphasic and hemiplegic and was transported on the following day to our institution. A left carotid angiogram revealed total occlusion at the origin of the middle cerebral artery.

He was subjected to surgery 108 hours after the onset of his symptoms. No change in his neurological status had occurred prior to operation except that it had become possible for him to wiggle slightly the toes of his right foot. Through a coronal incision and subfrontal approach, the left middle cerebral artery was exposed.

Hypothermia to 30.2°C. was used. At the point 2 mm. beyond its origin the vessel appeared slightly distended and a bit darker than normal. Mayfield temporary clips were applied upon the origin of the artery and immediately preceding the origin of the inferior lateral frontal branch. A longitudinal incision 2 mm. in length was made in the vessel over the obstruction. The temporary clips were relaxed individually, but no bleeding occurred. The clips were re-applied and clot was expressed manually until good bleeding could be obtained from either direction if the clips were relaxed.

The vessel was now closed with five 7-0 braided silk sutures. A great deal of difficulty was experienced in this. We had done no vessels at this depth previously and we had no instrument that would satisfactorily shorten and hold the vessel. A leak-proof closure with good through flow was obtained, but only after the vessel had been occluded for 40 minutes.

On the morning after operation he could still wiggle his right toes slightly and would obey commands such as squeezing his sound hand, or protruding the tongue. His condition was not deemed...
better, nor was it worse. He was discharged home 17 days after operation, there having been no change in his motor status. He had begun to say simple things, such as “thank you” or “well.” Angiography repeated 15 days after surgery virtually duplicated the original findings.

Case 2. Our second patient, a 33-year-old male power-shovel operator, had been well until 2 days preceding his admission. On that morning he had suddenly felt “weak” as he walked to work, and had fallen to the ground. He was unable to rise for one-half hour because his left lower extremity would not support him. At the end of that time, however, he recovered its function and worked a normal 8-hour day. He had no difficulty on the following day, but 2 days later, after working 2 hours, he again noted weakness in the left lower extremity and was taken to hospital. Shortly after arrival, he became hemiplegic. An angiogram was done 4 hours after onset of hemiplegia. This demonstrated an obstruction of the right middle cerebral artery, 1 cm. beyond its origin.

This patient was operated upon by two of us (LJW and JHJ) under hypothermia in the same fashion as in Case 1. Four mm. beyond the origin of the middle cerebral artery a small branch was noted with a second branch 2 mm. beyond this. Again beyond this, and some 8 mm. distal to the origin of the artery, a discolored dilatation was noted. A small transverse incision was made after the vessel had been occluded proximally by a Mayfield clip. After several small bits of clot and plaque had been removed, a single large fragment was brought from the lumen, at which time brisk back bleeding occurred, necessitating a distal Mayfield clip. The vessel was closed with three #7-0 braided silk sutures. The proximal temporary clip was removed 25 minutes after application. A good pulsation of the vessel in its entirety was noted. Hypothermia had been begun 10 hours after onset of complete hemiplegia. Good pulsations of the middle cerebral artery distal to the obstruction were first noted 16 hours after the onset of hemiplegia.

Six hours postoperatively the patient could move his left hand slightly and the left leg more. This gradually improved. He was up walking by his 4th postoperative day. He was discharged on the 16th day after operation, walking with a slight limp, but nevertheless able to sustain his weight on both heels and toes. There was a very mild left facial paresis on strong emotional effort. He used the left hand well for all but the most fine movements. Occasional grasping motion was noted of the hand, which had not been present prior to his occlusion, but he had for many years had the habit of drumming the fingers of this side. The grasping movement could be quickly abolished by calling his attention to it, but when his attention was averted it recurred. Angiograms done 12 and 34 days after operation show filling to a point 3 mm. beyond the original occlusion. A delayed (1 sec.) film demonstrates some filling of middle cerebral elements. It is believed this is collateral and not caused by patency of the middle cerebral trunk.

Comment. Although the first patient was believed to have an embolus and the second a thrombosis, a source from which embolism might stem was not demonstrated in either case. In both patients the vessel was rinsed with dilute heparin solution prior to closure, and removal of the temporary clamps, but anticoagulants were not used in either instance.

DISCUSSION

The surgery of arteries below 8 mm. to 10 mm. in size, certainly below 4 mm., has been
unsatisfactory because of the failure of patency both early and late. This is in marked contrast to the successful surgery of larger arteries. While this undoubtedly is in part attributable to the laws of hemodynamics, nevertheless, since the choice of suture material, styles of closure, etc., have been as available for use in the small vessels as in the large, it has appeared to us that one possible explanation is that a smaller margin of allowable error in placement of sutures exists in the case of small vessels. It has been felt that the fault has not been the inability of the hand to perform, but rather the inability of the eye to guide the performing hand. The dissecting microscope, so essential to the middle-ear surgeon, has been adapted to this purpose.

It was recognized early that what was true of the long-term results of normal animals was not necessarily true of diseased vessels of more aged humans. Still, the principles seemed sound, and experimental results were such as to encourage our use of this technique in the case of occluded middle cerebral arteries in 2 individuals. While both individuals have had neurological improvement, 1 almost to the point of normalcy, we claim no credit because their postoperative angiograms demonstrate a picture similar to the preoperative films. Rather we have placed these in the realm of failures, failures again, we believe, in technique:

1. The vessels were occluded for too long a period because we could not work with rapid facility at such a depth with the instruments available.
2. Our suture material was too coarse.
3. We could not remove the tension on the vessel during placement of sutures.

Steps have been taken to correct each of these faults:

1. New instruments have been developed and are now available to allow satisfactory shortening of the vessel for placement of sutures.
2. New scissors, forceps, and needle holders have been devised.
3. An ultrafine suture of monofilament Nylon has been produced.

It has been suggested that since good pulsation in these vessels was noted immediately after closure, and since our angiograms were not done for 15 and 12 days respectively after operation, the vessels may have remained open for a time, and then closed gradually, thus allowing time for development of small collaterals. This is a happy thought, but one for which we hold no personal brief. We do not see how one can prove or disprove this point, but in our next case we anticipate doing earlier angiography.

The upper limit of time between the onset of symptoms and surgical intervention is not known and must await clinical experience. While it is true that absolute anoxia will create destruction so rapidly that surgical intervention probably would never be justified, it also seems true that anoxia is rarely absolute.

Heparin and fibrinolyisin have not been used in our cases except to rinse the vessels about to be sutured with dilute heparin. We have not yet had sufficient experience with fibrinolyisin to express an opinion. We have refrained from the use of anticoagulants because of fear of hemorrhage in the postcraniotomy patient. It has not been found necessary to use either fibrinolyisin or heparin in the laboratory. Clinically we would not hesitate to use these agents if proven by further investigation to be helpful and, above all, safe. We have had no experience in the use of vascular glue and have been somewhat reticent to give up the security one experiences in a well-placed suture. However, in small vessels in which frequent sutures are required to promote hemostasis, we can readily appreciate that a satisfactory glue may considerably reduce the number of sutures required, thus shortening the necessary period of temporary occlusion.

SUMMARY

1. Instrumentation and technique for microsurgical reconstruction of small arteries are described.
2. Two cases are reported in each of which an obstruction was removed from the middle cerebral artery for early hemiplegia.
3. The work presented is of a preliminary nature. No conclusions can be drawn as to ultimate value. Further clinical trial seems justified.

REFERENCES


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14. SCHEIBERT, C. D. Personal communication.


DISCUSSION

Dr. J. Lawrence Pool: Dr. Jacobson and his colleagues deserve the greatest praise and credit for their experimental and clinical efforts to conquer the difficulties of surgery of small blood vessels. It is a field, I believe, that holds definite promise, not only for acute occlusive vascular lesions of the brain but also for the repair of arteries that may be injured during operations for intracranial aneurysms.

Having been interested in this problem for a number of years, I will endorse everything that has been said about the various difficulties in technique. However, the use of the Zeiss dissecting microscope is eminently feasible in the operating room as in the laboratory, as I can testify personally. Moreover, improved miniaturization of instruments and suture materials, as described, will, I am sure, also lead to greater effectiveness of this type of technical development. As the authors have said, even though closure of a small cerebral artery may lead to infarcted narrowing and ultimate secondary thrombosis, there is good reason to feel, as suggested in their second case, that sufficient arterial patency can last long enough to keep nerve cells viable until an adjacent collateral circulation develops.

We know, for instance, with severe vasoospasm after rupture of an aneurysm, that nerve cells may remain viable despite the presence of a greatly narrowed artery. We also know that effective collateral circulation can develop to a satisfactory degree when gradual arteriosclerotic occlusion of a carotid artery occurs. Hence we can hope that even if this type of small-vessel surgery fails to maintain permanent patency, it can at least offer a chance for collateral circulation to develop.

Finally, the matter of by-passing procedures might be mentioned. I once did such a by-passing procedure 10 years ago, with Dr. Robert Merrick, who is here, using a plastic tube to connect the superficial temporal artery with the anterior cerebral artery after the latter had been occluded following aneurysmal surgery. The tube successfully conducted blood from the external carotid system to that of the internal carotid system for at least an hour, as we could see, and then, of course, later thrombosed. This patient, incidentally, is still alive and perfectly well in spite of this procedure!

Dr. Samuel P. W. Black: I wish to compliment the authors on this technical advance which I believe could have considerable consequence in the study of the cerebral circulation and the diseases that assail it.

Their technique could, for example, be used to place upon the cerebral arteries, in experimental animals, vein-pouch grafts that simulate aneurysms, thereby allowing one to study more readily their effect upon the circulation.

The authors have demonstrated that the instruments used in ophthalmological surgery are quite adaptable to surgery on the finer cerebral vessels. I should like to know how small a suture the authors believe can be handled without the use of the dissecting microscope.

Several years ago, at our Detroit meeting, Dr. Gass presented an approach to the middle cerebral artery in which the lateral aspect of the sphenoid ridge was re-moved in order to gain the sylvian fissure. Have the authors considered that approach?

May I also inquire as to the possibility of the altered hemodynamics, which attended the hypothermia, hav-
ing been responsible for the anastomoses not remaining patent?

Dr. R. M. PAARDON DONAGHY: I should like to thank very much both Dr. Pool and Dr. Black for their discussion, and also to apologize to them because Dr. Welch and Dr. Murphey who were to have discussed this were not able to be here, and I surprised both of these gentlemen after they arrived by asking them for this discussion.

I would like to say in reference to the use of grafts or by-passes that are to last any period of time, Dr. Jacobson has in the laboratory done 18 Teflon grafts in 3 mm. vessels. Of these, 17 have closed, which we think is secondary to the growth of a new intimal lining, which has narrowed the lumen so far that closure has taken place.

Dr. Black, we have not considered the temporal approach, probably because we are more familiar with the other.

As to how small a suture can be used without the microscope, I am not certain. We have had difficulty using anything much less than 7 zero, and would have a great deal of difficulty, I am sure, with the new monofilament Nylon, as we also have had difficulty with the very fine tantalum wire in peripheral-nerve work.

I cannot answer the question as to whether hypothermia has had effect on the closure of these vessels or not. We did use hypothermia in both instances.

I would like to mention, however, that the application of this principle can also be used in the case of lacerations of the digital and facial nerves, and we are going to attempt repair of a facial nerve inside the skull in the next few weeks by this method. We are not advocating that each one dash out and buy one of these microscopes, but perhaps many of you could borrow one from your ENT colleagues. You will find with a little practice, you will be quite happy with it.

Immediately after the program this afternoon, Dr. Jacobson and I will have some of these instruments up on this table, if you are anxious to see them. You will find there are two principles that we have tried to develop. One is that one must see the suture, and, secondly, one must have the type of instrument that is proper, not like the ring handle which yanks the suture. This visit to Mexico City has, therefore, given me an opportunity to form a motto, perhaps, for our paper, which would go something like this: Suture, see; yank it, no.