Replantation of Extremities

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Despite a lot of lay literature on the subject of surgical replantation, it is very difficult, or perhaps impossible, for the conscientious physician to know at any given time where this sort of procedure fits into the surgical armamentarium.

I would like to try to summarize the information that is available, and to perhaps add some conclusions regarding the present status of surgical replantation.

One approach to this is to discuss four logical questions that might be asked about surgical replantation.

The first of these relates to technical feasibility, the second to problems of postoperative management, the third to the question of long range functional results, and fourth, and finally, to the team requirements for attempting surgical replantation.

TECHNICAL FEASIBILITY

Concerning technical feasibility, it is perfectly obvious that all of the surgical maneuvers necessary to reattach an amputated extremity have been standardized for many years. It is surprising that replantation was not attempted some years before it actually was, and there is still very little experience reported.

The case report from Boston stimulated our interest in the subject for a number of reasons. We began our work in the surgical laboratory by looking at the available experimental evidence to see what had been done with regard to the replanting of an amputated extremity. We found two or three published series, but these did not really give us a good idea of what could be expected in terms of reliability.

Amputation of the rear leg of dogs was done very carefully in the laboratory utilizing meticulous technique in order to keep the animal in the best possible condition. Under strict sterile technique the bone was sawed across and the blood vessels handled by ligating them and then cutting between the ligatures.

Once amputated, the extremity was simply put aside in the laboratory. No attempt was made to perfuse the extremity or treat it in any fashion except to try to keep it sterile. Following a period of time, the extremity was replanted.

Bone stability was achieved by using a plate plus a heavy intramedullary pin. We found that fixation was a matter of some importance. In the laboratory, as in the clinical experience, Dr. Gael Frank, of the Department of Orthopedic Surgery, worked out the technic and actually did the bone work.

The vascular anastomoses were performed using two standard vascular clamps, standard needle holder and five or six 0 silk depending on which was available. These anastomoses were carried out without use of microscopes or magnifying devices of any sort. Most of the anastomoses were done by Dr. Donald Carter, a resident in the laboratory at that time who had had no previous experience in vascular surgery.

In a total of 16 experiments, four animals failed to survive. The four that did not survive were animals who were under anesthesia for periods in excess of nine hours. Using nembutal in intermittent intravenous doses, it is not unusual to find that dogs will fail to survive a procedure of that length. These dogs simply did not wake up. We did not recognize any particular pattern to these deaths, and did not study the cause of death as carefully as I now wish we had. Of the 16 animals, 12 survived the operation and nine ex-
tremities survived. After the technic was fully developed, routine salvage of the extremity was clearly within the realm of possibility.

**LENGTH OF TIME**

The second technical problem had to do with the length of time the extremity might be disconnected and then be successfully replanted. From literature on the anoxia which various organs can withstand and survive, it is very clear that in the extremity the tissue most susceptible to ischemia is skeletal muscle. In other words, nerve, bone, and skin to some prolonged periods of ischemia better than do skeletal muscles. The work of Scully and others, suggests that skeletal muscle will probably survive about six hours of total ischemia before irreversible changes appear. This conclusion ought to be tempered by three things. First, the work was done on animals, and there is a good deal of species difference in tolerable limits to ischemia. Second, there are so many variables involved (condition of the cardiovascular system at the time of the ischemic episode, the temperature, etc.) that this experiment is particularly difficult to control. The third thing to remember is that none of the methods of prolonging this period of ischemia were carried out in any of these animals. It seems likely, at least, that hypothermia and perhaps the use of perfusion of the extremity with one sort of solution or another might favorably influence this period of time.

In the laboratory animals in which the extremity was ischemic between one and four hours, two of five operations resulted in a viable extremity. These were the early procedures; there is no claim for statistical validity.

In the subsequent series in which this extremity was ischemic between four and six hours, six out of six viable extremities resulted. This simply illustrates that the six hour limit is well within experimental tolerance at least under the conditions of our experiment. One animal survived after the extremity was off seven hours and 45 minutes. In this animal the extremity did stay viable, and we were not able to separate it from the others on the basis of subsequent changes.

No survival occurred among those animals in which the extremity was ischemic eight hours.

**POSTOPERATIVE MANAGEMENT**

Once it is agreed that replantation is technically feasible at least up to six hours after amputation, the second major question concerns the problems in postoperative management.

The initial problem, of course, is maintenance of circulation. In the extremity which is reattached swelling appears very promptly, being quite evident at the end of 24 hours, reaching a maximum point at about seven days, and then gradually subsiding. In most instances swelling is not noticeable after a period of two weeks. We did not observe in animals that the swelling was ever sufficiently extreme to result in necrosis. In other words, it was possible within the first hour to detect those animals in which the extremity was not going to survive.

I did see a patient, however, in another city in Oklahoma who had a really massive injury, and actually it was a tribute to the surgical team that they were able to achieve any sort of replantation. In this patient the swelling did progress to a point where it was obvious there was no venous flow and gangrene was the outcome in a period of about four days. There is little question, therefore, that a major problem in the immediate postoperative period is edema, and that this edema may, at least, compromise the circulation to a critical point.

We have just two partial solutions for this. The first is the realization that venous anastomosis is the critical point in surgical replantation. I think we worry too much about the artery and too little about the vein. The second solution involves measures which might be taken to reduce the swelling. At the present time we depend first, on elevation of the extremity, and second, on surface elastic compression.

The second major point in postoperative management has to do with the metabolic impact on the patient. The crush syndrome has been studied relatively well under a variety of similar conditions. I would refer you to the work of Eiken in which the results of replanting an extremity after prolonged period of amputation were carefully studied from a metabolic point of view. They concluded that the cardiovascular signs and symptoms that are observed (an increase in the pulse rate, a fall in the arterial blood pressure, in other words, shock) are due to exactly what one might think, a fluid loss in the extremity. They demonstrated nicely that the animal can lose 20 to 30 per cent of its plasma volume in the extremity in a fairly short period of time, and concluded from this that the major problem from a metabolic point of view simply is the loss of fluid into the injured extremity. It probably is not quite that simple; there is very clearly a vasodepressor agent that accumulates in the ischemic tissue. It has been debated for a long period of time what this is, it is still not clear, but it is there. It has been demonstrated recently very nicely by Dr. Campbell and his associates for an entirely different reason. But, again, clinically we might draw the conclusions that (1) one has to be prepared for a sizeable plasma volume deficit in these patients, and (2) there is massive bleeding from this extremity. Usually there is very little blood loss up to the time the extremity is attached. When the arterial circulation is restored, the marked vasodilation that has taken place in the extremity leads to marked bleeding. In our animals the majority of the blood loss occurred just
as soon as the anastomosis was completed. I mention this only because I think it is quite unlikely that this procedure can be done without facilities for multiple transfusions. We are talking about four, five or six units.

The item which influences whether or not replantation is a good procedure, is the extent of peripheral nerve regeneration. It is certainly beyond the scope of my remarks here to go extensively into the care of peripheral nerve injury, except to say that if one is going to do replantation, it should be realized that this is probably the most important single aspect of the patient’s care. However, the principles can be summarized as follows: (1) maintenance of position of function, (2) protection against trauma, (3) necessity for early attention to the joints, particularly of the hand, and (4) we have thought, at least, that early and repeated galvanic stimulation of the denervated muscle is helpful. This is debatable, but at least it is the thinking of the people at our particular institution. Nevertheless, one has to be prepared to carry this out over a very long period of time, perhaps a minimum of two years.

LONG-RANGE RESULTS

Now the third major point to discuss is the long-range results. You cannot really decide whether or not surgical replantation is indicated until you know what the patient might be able to expect in terms of functional recovery. There have been only two cases of total replantation of the extremity reported in scientific literature. Unquestionably, there have been other cases done, but we do not know what the long range results have been. You are aware, I think, that the two cases done in Boston, one with a follow-up of approximately two years, and the other with a follow-up of approximately one year, have been carefully reported. In both instances the return of sensation and musculoskeletal function has been very encouraging. It is not 100 per cent, but it certainly is far better than any known prosthesis might have furnished these patients.

We fall back on a total experience of two instances to decide whether or not the long-range result is good or bad. I think that we will have to leave this by saying that more cases must be reported in detail over an extended period before we can really decide what the functional result might be.

We did try to study this in dogs, but it is not possible to give very good physiotherapy to dogs. However at least we might be able to get some idea as to what the animals do in the follow-up period. There are only two reports of animal series that discuss any long-range follow-up. One involves a Russian and was published in the New York Academy of Science publication. He reported that at the end of six months the dogs were perfectly normal. Perhaps dogs are different in Russia, but this certainly is not true in the United States.

The other series which has been done and which has been reported indicates what we found in our own dogs. In our experiment, six of nine animals were followed between 12 and 16 months. Of the six followed 12 to 16 months, four were bearing weight. The other two had severe contractures in the knee joint, which meant that they ran around on three legs with other leg tucked up underneath them.

Of these six dogs, two had persistent swelling. Both of these had injection at the site of the fracture line, and at autopsy this injection was around small bone fragments. In the human it would almost surely have responded to sequestrectomy. Three animals had draining sinuses, and these draining sinuses led to the fracture site in each instance and each was simply a chronic osteomyelitis at the fracture site. This, too, might very well have responded to treatment which was not given. We were simply trying to find out what these animals would do. So our experience with dogs who got no treatment would indicate that a certain degree of functional recovery occurs, and so this topic is very much unsettled. Certainly one shouldn’t get very enthusiastic about replantation until it has been demonstrated repeatedly that there is a sufficiently good functional result in terms of several years to make prolonged physiotherapy, time lost, etc. worthwhile.

REQUIREMENTS FOR REPLANTATION

Finally, we might say something about the requirements for replantation as the fourth major heading. The requirements for replantation include (1) a surgical team which includes people who are available in almost every sizable hospital, and (2) a surgeon who has the ability and the equipment to deal with a fairly complicated comminuted fracture. The exposure is superb, and this really is not beyond the realm of almost anyone who knows anything about orthopedics. Methods of fixation, of course, can be the subject of endless debate. There are probably several ways of doing this satisfactorily. There must be a surgeon, a vascular, general, or thoracic surgeon, with experience in dealing with peripheral vascular surgery. The simple routine methods should be adequate. Finally, we felt that it is quite helpful to have more than one general surgeon in order to carry out the procedures on the amputated extremity concomitantly with carrying out the procedures and debridement of the amputation site. So the surgical team in our own institution consists of (1) one orthopedic surgeon, and (2) three general surgeons, one of whom is a resident.

We might bring up three points that are important as far as this team goes. The first involves some knowledge of preservation of the extremity.
At this time there is very little data, but we have strong feelings that hypothermia ought to extend the permissible time between amputation and replantation. This simply can be done by immersion in cold water.

The second point is the necessity for careful debridement of both ends. The muscle damage with subsequent foreign body reaction and inflammation surely must add to the edema that is found routinely.

Thirdly, the team must have some idea of priority of repair. In animals, and in our single clinical experience, we felt the bone should be repaired first, followed by the veins, followed by the arteries, followed by the nerves, muscles and skin, in that order. One must remind the orthopedic surgeon to shorten this bone. Both Dr. Frank and I knew this at the time of our own experience, but everything looked so good we did not do it; then when we started to sew the muscles together, we had to stop and shorten the bone.

Finally, we think probably that the vascular bed of the extremity ought to be perfused by simple gravity perfusion. The end of a sterile I.V. extension tube is an ideal cannula. It fits very nicely into the artery. Our own choice has been Ringer's lactate to which we add penicillin or whatever antibiotic you prefer, and heparin.

Finally the team which undertakes to do this must have at its disposal long range facilities for very careful and complete physiotherapy.

I would like to tell you about the one case we have encountered because I think it illustrates a number of problems and perhaps emphasizes that there is some reason for optimism in the management of such injuries. This patient is a 20 year old college student at Oklahoma State University. Oklahoma State is a very basketball oriented school, and this was a 6'9" extraordinarily well-coordinated basketball player; this made him the subject of a great deal of interest to a lot of people, particularly at O.S.U.

He was working at an athletic dormitory and reached into a high speed water extractor. A piece of clothing apparently wrapped around his arm, and at extremely high speed this arm was simply torn off midway between the shoulder and the elbow. This is structurally the weakest point in the upper arm, and thus it occurred at exactly where you would expect it to occur. Incidentally, this is almost identical with the first case done in Boston.

Fortunately, the physician who was called to see this young man knew of our interest, and he called Oklahoma City within a few minutes after the accident. Also fortunately, the boy's roommate was a premedical student who actually knew something about the preservation of extremities primarily from an article in the state medical journal. He immediately put the arm in a tub of ice. The boy was in Oklahoma City, a distance of about 70 miles from Stillwater, within a couple of hours. He was in the operating room within three hours after the injury, and arterial flow was established almost exactly five hours after the injury.

The muscle and skin closure was perfectly routine in this young man. He was returned to the ward, and on the morning after the operation the color of his forearm was good and remained good.

In one week you could see that there was some swelling of the forearm. The finger color remained good. The cardiovascular state remained the same. He was started on physiotherapy within a few days of his injury and by the end of the week he was getting full rotation, movement of the finger joints, and he was beginning to get skeletal muscle stimulation using a galvanic stimulator.

At the original procedure the nerves were tacked together because they were attenuated to quite a marked extent. We could not identify the distal radial and felt that further extensive dissection in this extremity might cause too much tissue damage.

Several months following the replantation he was reexplored. At this time, the median nerve was joined by direct suture after taking about a 10 cm. segment of neuroma out, and a free nerve graft was used to unite the ends of the ulnar nerve which had a neuroma of approximately the same length which even by rerouting we could not shorten enough. After another month and a half, the radial nerve was repaired using a second free graft.

At the end of a year by examining the patient it was apparent that the distal biceps were innervated. He had excellent shoulder and elbow motion. He now has movement in the finger flexors which is very definite and to a fair degree. He has no strength of consequence in the finger flexors yet. Several of the forearm flexors are now innervated, and he has a protective level of skin sensation down to the wrist.

It is too early to know exactly what his functional result will be, but if he continues at the rate he is going, it certainly will be satisfactory. This boy actually has lost little time from school. He went back to classes in January. He came up for his nerve graft procedures at convenient times and lost no significant amount of schooling as these procedures really only involved a hospital stay of a few days.

**SUMMARY**

Perhaps we can summarize by saying that replantation is a technically feasible procedure at the present time. If one does undertake this, the patient is committed to an extremely long-range physiotherapy and rehabilitation program. The third point, the degree of functional recovery, is still a matter for clarification, and until this is clarified, we need to be guarded about the indication for replantation.
Finally, I might point out that the techniques and procedures learned or encountered in this maneuver may have application in other fields just around the corner.

REFERENCES


Mercy Hospital Medical Day

Questions and Answers

Dr. E. J. Drew: What did you use for the nerve grafts?

Dr. Williams: We used the median antibrachial cutaneous out of that arm for one and the saphenous nerve out of the opposite leg for the other.

Dr. P. R. Holzworth: What was it that necessitated the shortening of the bone?

Dr. Williams: The muscles.

Dr. Holzworth: How much shortening was done?

Dr. Williams: About an inch. Vascular anastomoses are easy at full length, but the muscles would not go back together. After 18 dogs we knew this, but at three o'clock in the morning maybe we do not think as clearly as we would like to.

Dr. A. N. Smith: What would be your thinking in an extremity that did not have too much soft tissue damage but an extremely comminuted bone? What would you do here?

Dr. Williams: Perhaps there are others here who would know more about this bone thing than I would. If there was any possibility of getting bone continuity by circumferential wiring, if necessary, I would try. I suppose that you might put intramedullary pins and leave a gap. These are things that I really do not know about. It seems to me that reconstruction of bone has reached a pretty advanced state. I would not like to let that stop me even if we had to shorten it with the idea of lengthening it later. I know there are a number of orthopedic experts here. Dr. Dubansky?

Dr. M. H. Dubansky: I would agree with you.

Dr. J. H. Kelley: I can add nothing further from my experience.

Dr. Drew: How long did you leave this man on anticoagulants following surgery?

Dr. Williams: I am sorry, I should have mentioned this. We did not use anticoagulants after operation in this boy or in the animals. I feel that an arterial anastomosis that is booming will seldom thrombose. I think the grief from the anticoagulants exceeds their value.

Dr. Drew: When you anastomose the arteries and veins, why do you not put some cellophane or glass cannulas in there and then later go in and take these glass cannulas out?

Dr. Williams: Well, of course, you realize that glass might not be first choice, but there have been numerous attempts to develop anastomotic tools. Some of you may remember the Freyfoogel couples, a few years ago, and there are others including the Russian stapling device. I would submit that both of these vascular anastomoses could not possibly have taken more than 35 minutes apiece. What took all the time was the fact that when you reestablish arterial flow, the Simeon phenomenon is clearly demonstrated, unbelievable bleeding from the distal muscle edges. This boy was extremely muscular. His arm at the amputation site was as big around as my leg above the knee, and we lost four bottles of blood out of those distal muscle ends within a few minutes, and spent about three hours clamping and tying bleeders in the distal skeletal muscles. This was not as much a problem in the dogs because we clamped them on the way in. Much time involved is in cleaning up and suturing muscles back together. However, I agree with you that if something could be worked out to permit rapid vascular anastomoses, it would be nice. What the Russians are doing, however, is not just trying to do it fast, they are trying to arrange for technicians to do it. There are just too many people in Russia and too few doctors.

Unidentified: What about sympathetic block?

Dr. Williams: If this extremity wasn't denervated sympathetically, we will never see one. We talked about this, and there was just never any question but that the circulation in this extremity was all right.

I subsequently have seen the patient which I mentioned to you, so maybe now I would be a little more scared. This patient who failed did have stellate ganglion blocks, but was clearly a problem in inadequate venous return. This is why, incidentally, the partial amputations have done well. I am personally convinced that the reason why these extremities survive is that the venous
return is preserved. Bone would be an ideal place for venous return.

_Dr. Kelley:_ What about the below the knee and below the elbow? Would the problems in this be about the same?

_Dr. Williams:_ Well, I would try it below the elbow, John. However, I think that this whole thing regarding the lower extremities is questionable. This boy went to school with his denervated upper extremity. I can not imagine that you could do anything gainful with the totally denervated lower extremity.

_Dr. S. W. Dusdieker:_ How do you get the blood clots out of the arteries? Or out of the veins if the arm has been off for an hour or so?

_Dr. Williams:_ Well—we just hook up a standard I.V. and insert it into this. There is a sterile extension tubing that I am sure your anesthesiologists have. It fits nicely into the artery. Just let it flow by gravity. Surprisingly enough, there were no clots there. This is also true in animals. When we come down to it, we know an awful lot about why blood clots, but we do not know much about why it does not clot. Intravascular thromboses are still mysterious. Blood will stay liquid in isolated vessels for a long period of time.

_Dr. H. G. Ellis:_ What criteria did you decide on for this amputation? Did you set up a criteria that has certain standards for certain conditions which you use to hang on to, or for what conditions to show up? I am thinking about the crush syndrome patients. How long would you let a patient go before you amputate?

_Dr. Williams:_ Well, I think that any time I thought the patient's life was in danger from the extremity, I would amputate. Ordinarily, however, I believe this would be when I did not think that extremities would stay viable and survive. I think if they are really questionable, they are going to have to go. We all have difficulty in making this decision, probably we should not have, maybe this is the time to get somebody else to come and look.

_Dr. J. L. Molchan:_ What do you think that interruption of the lymphatic channels has to do with the development of the edema?

_Dr. Williams:_ I am not sure, but I am sure that it has some.

**Auto Fatalities Increase**

A worldwide increase in motor vehicle accident deaths during recent years is evaluated in a summary appearing in a recent issue of the Metropolitan Life Insurance Company's STATISTICAL BULLETIN.

In the United States the motor vehicle accident death rate has increased each year since 1961, from 20.8 per 100,000 population to 24.5 in 1965, a jump of 18 percent in the short span of three years. Canada, where the upturn started a year earlier, recorded a 22 percent increase in four years, from 20.7 in 1960 to 23.3 in 1964. Even sharper rises have taken place in some European countries. Finland and Italy registered increases of about 40 percent between 1959 and 1963, with accident death rates in the latter year only slightly below those in the United States. Both France and Sweden experienced increases of 25 percent during the period 1959-64. The upturn was more moderate—15 percent—in England and Wales, where the rate in 1964 was 15.3 per 100,000.

In 1963 the motor vehicle death rate per 100,000 persons in Japan was 15.7, nearly a third higher than that recorded in 1959. Australia and New Zealand registered relatively small increases between 1959 and 1964.

When the degree of motorization is considered, the United States, which leads all nations in number of motor vehicles per 100 persons, has the lowest accident death rate, 52.6 per 100,000 registered motor vehicles. Pedestrian deaths accounted for 17 percent of the total number of motor vehicle deaths in the United States.

Among the countries reviewed, Japan had the highest death rate based on motor vehicle registrations—402 per 100,000 vehicles. Even though the number of cars in that country had increased fourfold since 1959, there were only four motor vehicles per 100 persons in 1963. It is probable that many new and inexperienced drivers contributed heavily to the toll. As in other countries where there have been sudden large increases in the number of motor vehicles on the road, it has not been possible to construct the necessary good roads quickly enough nor to enact the traffic laws required to meet the changed conditions.

**Offer Heart Booklets**

Four new booklets concerned with major aspects of heart examination have been issued by the American Heart Association and are available for use by interested physicians.

The series, a project of the Association's Committee on Medical Education, is entitled EXAMINATION OF THE HEART, and replaces a single book of the same title which is now out of print.

The booklets are divided in subject matter as follows:

**PART ONE:** HISTORICAL TAKING by Howard B. Sprague, M.D., Boston.

**PART TWO:** INSPECTION AND PALPATION OF VENOUS AND ARTERIAL PULSES by Noble O. Fowler, M.D., Cincinnati.

**PART THREE:** INSPECTION AND PALPATION OF THE ANTERIOR CHEST by J. Willis Hurst, M.D., and Robert C. Schlant, M.D., both of Atlanta.

**PART FOUR:** AUSCULTATION by James J. Leonard, M.D., and Frank W. Kroetz, M.D., both of Pittsburgh.

Copies may be obtained from the Iowa Heart Association, 529 Thirty-sixth Street, Des Moines, Iowa 50312.