Replantation of Amputated Extremities: Present Status

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In May 1962, an amputated human extremity was successfully reattached for the first time. The patient was a 12-year-old boy who sustained amputation of the right arm in a train accident. He was taken to the Massachusetts General Hospital where Dr. Ronald Malt assembled a surgical team and reattached the extremity.¹

As is usually true, the MGH success was the culmination of many years of interest and research in the field of re plantation. Numerous legends, caricatures, and crude accounts demonstrate that for several centuries, men have been interested in replanting amputated parts. It is hardly surprising that early attempts were not successful.

The first scientific experiments dealing directly with re plantation were begun by Dr. Halsted in 1882, when he divided all the structures of a dog leg except the femoral artery and vein, repaired the severed structures and then, after varying intervals, divided the artery or the vein. His interest was generated by observing postmastectomy edema. It is extraordinarily interesting that Dr. Rienhoff participated in some of these experiments. Dr. Halsted did not publish this work until 1922, and his early experiments were not generally known prior to publication.²

In 1903, a German investigator, Hopfner, divided all structures of a dog limb, resutured them and had one animal live for 11 days with a viable limb.³ Carrel and Guthrie did the same thing in 1906 and had an extremity survive for about 72 hours before it became gangrenous.⁴ It is of current interest that Carrel actually transplanted a limb from one dog to another in 1908 and this extremity survived in a viable state for three weeks.⁵ Following this flurry of scientific interest in re plantation, very little experimental work was reported in the years after 1908, although it is obvious that the development of vascular surgery during this period of time contributed a great deal to the knowledge that would ultimately lead to re plantation.

In 1960, a Russian scientist, Lapchinsky, reported many experiments on limb re plantation in dogs and was able to replant extremities in a small percentage successfully.⁶ The work of Lapchinsky and, perhaps more importantly, the clinical experience of Malt resulted in renewed interest in the subject of re plantation.

In 1962, Dr. Donald Carter and I decided to try to answer a few questions not clarified by the experimental work reported previously.⁷ The hind limbs of a series of dogs were amputated using a meticulous, sterile technique. When the procedure was completed, the dog leg was simply put aside in the laboratory and no attempt was made to influence its temperature. No perfusion or anticoagulant therapy of any sort was given any animal. After varying periods of time, we surgically replanted these extremities.

Dr. Gael Frank, from the Department of Orthopedic Surgery, worked out a method of fixation of the femur in the dog (which is somewhat more difficult, interesting enough, than it is in the human). Dr. Frank also collaborated in our clinical experiences. The bone is stabilized first because the necessary orthopedic hardware could rip asunder any vascular anastomoses that preceded. Following repair of the bone, the vessels were sutured. One rapidly learns to do the venous anastomosis before the arterial. A question asked of these experiments was whether the vascular anastomoses could be done with routine instruments and techniques since, at that time, we and others were interested in magnification techniques. As illustrated in Figure 1, routine

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vascular surgical instruments were used with no magnification of any sort. Following repair of the vessels, the nerves, muscles, and skin were sutured and the animals allowed to recover. At varying intervals, the long-range survivors were sacrificed and autopsies performed.

These experiments were designed to answer three questions. The first question was simply how often can one replant an extremity with success in the animal. In a total of 16 experiments, four animals died before the experiment was completed. Of the 12 animals that survived the operation, the extremity survived in nine. These results indicated that the procedure of replantation can succeed in salvaging the extremity in a high percentage of experiments.

The second question concerned the importance of time in successful replantation. When replantation was completed between one and four hours after amputation, two of five animals survived. All three operative failures were in this group. After four to six hours there were no failures in six attempts. In the one animal that survived replantation after six hours, the extremity survived. Four animals were lost in attempts to enlarge this group. The cause of their death is a matter of interest and current investigation.

The third piece of information sought was some idea of functional return. All we could really say about the animals is that a large percentage of them did walk on the extremity. Almost all would withdraw from painful stimuli which indicated some return of sensation. There is no question that the extremity was not normal. All the animals had a foot drop. This answer is obviously less complete in terms of clinical application than the answers to the other two experimental questions.

These experiments and many others, of course, have added a good deal of information to the field of replantation. Clinical reports have begun to appear with regularity following the Malt report. Up to the present time, there are in excess of 50 human replantation operations reported in the literature. Many of these are in obscure foreign journals, and it is difficult to give an exact number because these reports have been picked up and added to other series. Clinical reports vary enormously in completeness and accuracy and a great deal in the length of follow-up. The information gained from reviewing the collective series is helpful but should not be considered conclusive.

General Points

The first general point that might be made is an observation regarding the age of the patients. Replantation of extremities has been performed from age 2½ years to nearly 60 years. The best results have been in young patients. The 2½-year-old child reported by Rosenkrantz probably has the best result of all reported upper arm replantations. The observation that young people do better, of course, is commensurate with the long-known fact that nerve regeneration is more complete in young people. Replantation should rarely be attempted in a person past middle age.

A variety of wounding agents has been encountered in the collected experience. Clean, incised, distal amputation sites give better results than avulsion injuries or other types of crushing injuries. The best results have been in guillotine-type injuries. Contamination of the wound is a relative contraindication to an attempted replantation.

There are no reports of long-range successful replantation of lower extremities, although several attempts have been reported and several others are known. The reason for this is principally the difference between function of the hand and of the foot. The anesthetic, shortened leg is indeed a hazard to the patient. At the present time it seems prudent to suggest that lower extremity replantation not be attempted until we can deal more effectively with peripheral nerve injury. One of the "spin-offs" of the experience with replantation has been the salvage of badly damaged but incompletely amputated extremities. There seems to have been a tendency to more completely assess pa-
patients with badly injured extremities, both lower and upper, and to operatively salvage some that undoubtedly would have been summarily amputated even a few years ago. I think this is indeed an important aspect of the interest in replantation.

It is obviously important to know how long after amputation replantation might be successful. There is a good deal of evidence that skeletal muscle will survive at normothermic temperatures up to six hours and probably up to eight hours. Clearing the vasculature by perfusing it with a balanced electrolyte solution should extend this period. Cooling has been the time-honored method of preserving the extremity. In the Russian experience, one extremity was successfully replanted 24 hours after its amputation, having been cooled during that period of time. The likelihood of infection and the marked accentuation of the cardiovascular effects of revascularization lead to the suggestion that replantation not be considered when the time interval between amputation and restoration of flow is likely to be beyond eight hours. This is conservative, but it is of interest that in the reported experience no extremity has survived after an ischemic period exceeding more than seven hours.

The technical aspects of replantation have been pretty well standardized. It is extremely important to shorten the bone. This allows muscle repair. It is not necessary for vascular and nerve repair, although it is helpful. Bone fixation can be by whatever method seems most appropriate. The venous anastomosis follows and as many veins as possible should be repaired. It is almost mandatory to restore two veins. This is followed by arterial anastomosis, which is easier and which technically creates fewer problems than the venous repair.

The management of severed peripheral nerves is controversial and beyond the scope of this paper, but the tendency has been to do primary repair of the nerves only in those relatively rare situations in which the nerves have been cleanly severed. The most common method of handling the peripheral nerves has been to do early secondary exploration and formal secondary repair. The current methods of handling peripheral nerve injury represent the greatest single limitation in the field of replantation. The closure of skin and muscle is routine, but most have felt that drainage of some type is indicated.

The problems encountered in the postoperative period in our own experience and that of others might be divided into problems which are encountered early and those that are encountered late. The most obvious early problem is failure of the circulation. This is more commonly due to inadequate venous drainage than to lack of arterial inflow. Failure of the circulation is not subtle. Generally, one can tell within an hour or two of the replantation procedure whether or not the circulation will be adequate. The most common cause of early failure, both clinically and experimentally, is infection and this leads to emphasis on thorough debridement. Occasionally, in experimental animals and in humans, shock has been reported, usually beginning within an hour after the circulation is established. The cause of this shock is debated. Dr. Blalock pointed out that this phenomenon was due to plasma loss into the injured area. Lapchinsky and others have raised the possibility that a toxic substance elaborated in the ischemic extremity is released into the circulation when the extremity is revascularized. The bulk of experimental evidence is that the explanation for the cardiovascular collapse which is occasionally observed after revascularization is due to plasma and fluid loss into the extremity and wound. It is clear that there is return of blood with a relatively low pH from the extremity. This is, to a lesser extent, the phenomenon that has been nicely described by Dr. Mansberger some years ago. Even with long periods of single extremity ischemia, the result to the systemic circulation in terms of pH is not catastrophic and, in fact, usually not measurable. Nevertheless, the necessity for giving fluid and occasionally for using bicarbonate or amine buffers should be kept in mind.

Late Complications

The late complications which have resulted in failure are due to faulty or incomplete neural regeneration. In at least one patient, pain beginning in the relatively early postoperative period was sufficiently persistent and severe that reamputation was indicated a few weeks after the original procedure. Obviously, an anesthetic, useless extremity with no joint function is a hazard to the patient and should be removed. It is important to realize that the function of a replanted extremity should be compared with prosthetic function and not with normal.

The definition of success in replantation is difficult. For purposes of this review, I have arbitrarily decided that if the patient and his surgeon agree that the extremity function is preferable to a prosthesis two years after injury, the procedure is considered a categorical success.
Using this admittedly inadequate criteria, about three fourths of the reported cases have resulted in a successful outcome.

My personal experience with replantation, like that of most others, is limited. In December 1969, an 11-year-old boy was grinding hog feed in a hog pen in Wichita Falls, Texas. Somehow, his arms became entangled in a conveyor belt and both arms were amputated and dropped into the hog pen. The boy was flown to Oklahoma City, arriving less than two hours after his injury. On arrival, the patient was in good general condition. Despite massive contamination of the wounds and principally because of the age of the patient, a decision was made to attempt replantation. All wounds were cleaned, irrigated and debrided (Figure 2). The circulation of both extremities was cleared using Ringer’s lactate with a small amount of heparin and an antibiotic solution. There were long nerve ends protruding from both shoulder wounds, indicating avulsion-type injury (Figure 3). Reimplantation was carried out on both sides. Revascularization attempts were completed within eight hours of injury. The left extremity never did well, exhibiting early evidence of venous failure. At fasciotomy several hours after the original operation, arterial bleeding was still present. This arm was amputated at 48 hours. Massive infection occurred in the right wound. After two weeks, gangrene of the finger tips progressed to the hand necessitating amputation at mid-forearm 18 days after the injury.

The right arm has now been fitted with a prosthesis and the elbow is helpful to him, although it is probably not worth the price paid in risk and prolonged illness. At least two relative contraindications to replantation existed in this patient. The degree of contamination was truly massive. In addition, extensive nerve avulsion is usually associated with poor nerve regeneration. Faced with a similar situation today, we would probably pick out the better of the two extremities and attempt to replant a single extremity. The procedure is of interest, however, for several reasons. It clearly demonstrated technical feasibility. Also, there were no observed cardiovascular complications.

Our initial experience with replantation involved a 20-year-old basketball player who reached into a commercial water extractor while the machine was still operating. His upper extremity was instantly amputated. An idea of the force involved can be gained from the fact that the patient was not knocked off his feet. His companion was a premedical student (subsequently a house officer in Baltimore) who knew about the necessity for cooling the extremity. The patient was transported 70 miles to the University of Oklahoma Medical Center, arriving about two hours after the accident. The patient was in excellent condition and had sustained almost no blood loss. This extremity was in good condition, having been amputated in a very clean environment (Figure 4). The nerves were avulsed for several centimeters, but the other structures appeared to be cleanly divided. The replantation procedure was carried out exactly as has been described. The extensive comminution of the humerus was repaired by shortening and with multiple screws and plates. Two large veins were anastomosed, followed by
the brachial artery. The nerves were loosely approximated. Muscles and skin were sutured by routine methods. There was never any question about viability of this extremity. The patient showed no systemic effects that we could recognize; however, he did receive blood during the operation. Swelling of the extremity reached a maximum at one week, gradually began to subside over the next several days, and was almost gone at the time the patient left the hospital on approximately his twentieth hospital day.

Subsequently, two operations for repair of nerves were performed. After three months the median and ulnar nerves were repaired—the ulnar using a long graft and the median simply by suture. Later, through a lateral approach, the radial nerve was repaired using a long nerve graft.

At present, this patient has good gross function of his extremity (Figure 5). He has a protective level of sensation in the arm and hand, but it is not very accurate. He knows that something is hot or cold or painful but cannot accurately localize it, and his two-point discrimination is about 2 cm over most of the hand. This is considered preferable to any of the prostheses that have currently been made available.

In summary, replantation ought to be considered in all instances of amputation of the upper extremity. The factors that particularly favor such an attempt are youth and a clean, preferably distal, incised wound. The principal limitation in replantation is inability to obtain predictable peripheral nerve regeneration. Nevertheless, the chances in favorable circumstances of achieving a good result are approximately 70%.

REFERENCES

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