Replantation of Amputated Extremities

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The possibility of replanting a useful extremity after amputation has interested surgeons for many years. However, there is surprisingly little scientific literature on this subject. The purpose of this communication is to report experimental and clinical observations pertaining to replantation of amputated extremities.

Material and Methods

In the surgical laboratory, the left rear limbs of unselected, anesthetized, mongrel dogs were carefully amputated just above mid-thigh, using sterile technic. The femoral artery and vein were doubly ligated, and divided between ligatures. The bone was divided by an oblique osteotomy. The amputated extremity was wrapped in a moist, sterile drape and put aside. No perfusion or anticoagulants were used, and no attempt was made to influence temperature of the amputated extremity. After varying periods of time, replantation of the extremity was begun. The femur was shortened approximately 2 cm. by making a second oblique osteotomy parallel to the first. The femur was then stabilized using an intramedullary nail and a plate at the line of division. Vascular clamps were applied to the vessels and the ligated ends trimmed away. The venous anastomosis was performed with 5-0 or 6-0 aterial silk, using standard over-and-over continuous suture technic. The artery was then repaired in the same fashion. On removal of the vascular clamps, immediate distal arterial pulsation and bleeding from the distal muscle ends indicated restoration of circulation. The sciatic nerve was repaired with interrupted fine silk sutures in the perineural sheath. The muscles were approximated with chromic catgut and the skin with subcuticular chromic catgut. Following operation, the animals were returned to cages, and, other than intramuscular penicillin, no medications were given. The animals were observed until healing of the skin was well established and then were kept at an animal farm and observed at intervals. Arteriography was performed on all animals by passing a catheter to the aortic bifurcation from the opposite femoral artery and injecting contrast media. Surviving animals were sacrificed and autopsied 12 to 16 months after replantation.

Results

Figures for survival and extremity survival are listed in Table 1. In the four animals who did not survive operation, replantation was attempted 8 hours after amputation. The animals were anesthetized during this entire period of time with intermittent doses of pentobarbital (Nembutal). Respiration was maintained by a simple piston respirator and endotracheal tube. Previous experience in the laboratory has indicated, however, that dogs survive this type of anesthesia for prolonged pe-
TABLE 1. Surgical Replantation Experiments

<table>
<thead>
<tr>
<th></th>
<th>Total operations</th>
<th>Surgical survival</th>
<th>Extremity survival</th>
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<tr>
<td></td>
<td>16</td>
<td>12</td>
<td>9</td>
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periods of time rather poorly. The animals died without regaining consciousness and within 2 hours of termination of the procedure. Of 12 surviving animals, gangrene of the amputated extremity developed in three. These were experiments 2, 4, and 10. Experiment No. 10 was the only instance in which thrombosis of the vein was noted prior to beginning the venous anastomosis, and, although thrombus material was extracted, removal was obviously either incomplete or early thrombosis recurred. Failure of circulation in the three extremities was obvious early in the postoperative period, and viability of the extremity was never in doubt for more than an hour or two after the procedure. Prior to sacrifice of these three animals on the second or third day, arteriography revealed occlusion of the artery at the line of amputation.

Replantation was carried out at intervals following amputation, and the success rate at varying time intervals is recorded in Table 2. The time referred to is the interval between final severance of the extremity and restoration of circulation. Replantation with early survival of the extremity can be achieved in a high percentage of operation following six hours of circulatory interruption. Several operative deaths were encountered in trying to add experiments in which the extremity circulation was not re-established until 8 hours after amputation.

Although color and temperature of the extremities remained good, edema was noted early in the postoperative period and reached a moderate to marked degree from 2 to 7 days after operation. This subsided slowly in the majority of animals. In two animals, there was moderate residual edema at the time of sacrifice, over a year after replantation. In both animals there was a sinus tract to a sequestrum at the site of bone repair, and in one of these animals thrombosis of both artery and vein was noted at autopsy. Surviving animals were observed at infrequent intervals after transfer to a farm facility, and no attempt was made to train the animals or to influence return of function. Arteriograms, performed in surviving animals at intervals ranging from several weeks to several months after replantation, indicated normal arterial and venous circulation. Of the 9 animals with viable extremities after replantation, 3 died within 2 months of operation. One animal died while being anesthetized for femoral arteriography 2 weeks after operation. At that time there was no question of viability of the leg. Three weeks after replantation one animal chewed the viable, replanted extremity severely, and this animal was sacrificed. The third animal died at the animal farm 6 weeks after replantation. No autopsy was performed on this animal, but the extremity was observed to be viable shortly before death of the animal from an unknown cause.

Surviving animals were sacrificed at 12 to 16 months after replantation. Some observations of limb function and condition are tabulated in Table 3. The replanted extremities appeared relatively normal, but muscle atrophy was apparent on close inspection (Fig. 1). Animals which regained weight-bearing walked with a definite limp, and there was foot drop in each animal, resulting frequently in weight-bearing on the...
top of the paw. Animals which did not bear weight carried the extremity with the thigh and knee flexed and contracted in this position. In all instances, at autopsy the vessels were patent, with the exception of one dog described above in which the vascular anastomoses were adjacent to a large abscess at the site of the bone transection. It is thought that thrombosis occurred secondarily in this animal. Bone union was stable in all animals at autopsy.

Case Report

Shortly after midnight, on November 1, 1964, a 20-year-old white male college student was admitted to the University of Oklahoma Medical Center following amputation of the right upper extremity. The accident occurred approximately one hour earlier when the patient reached into a high speed commercial water extractor in an athletic dormitory. Apparently, wet clothing caught the arm and instantly wrenched it off. The patient's roommate, a pre-medical student, dressed the amputation site with a towel and wrapped the extremity in a towel dipped in ice water. At the college infirmary the extremity was placed in ice, and Medical Center personnel were notified that the patient was in transit. On arrival at the University of Oklahoma Medical Center, 70 miles from the site of the accident, the patient was in excellent condition. His vital signs were normal, and he complained of little pain. The patient was promptly taken to the operating room, which had been prepared while the patient was in transit. The amputation site was quite clean, and the muscles appeared to have been sharply cut. The arterial end was visible and pulsating, but there was little bleeding. The nerve ends protruded and were attenuated. The wound was minimally debrided, and vascular clamps placed on the major vessels. A second team carefully cleaned the amputated extremity, debrided obviously fragmented tissue, and perfused the vascular system using a standard intravenous set with a sterile extension tube (Fig. 2). The perfusate consisted of 1,000 cc. of normal saline containing 50 mg. of Heparin and 10,000,000 units of penicillin. Prompt return of the perfusate was visible from the vein, and no large clots were extracted. The orthopedic member of the team joined the extensively comminuted fragments of mid-humerus, using multiple screws and two plates. The humerus was shortened approximately one inch (Fig. 3). The venous anastomosis was performed using interrupted sutures of 6-0 silk, and the arterial anastomosis performed in a similar fashion. On opening the clamps, good circulation was immediately evident. Profuse bleeding from the distal muscle ends was controlled for a few minutes by packing and then by a long and tedious process of clamping and ligating bleeding points. Three units of blood were given. Circulation was re-established almost exactly five hours after the amputation (Fig. 4). The musculocutaneous nerve was identified, and anastomosis between the two ends performed. The remaining nerves were badly attenuated, and it seemed impossible to determine the exact extent of nerve damage. The median and ulnar nerves were informally anastomosed, and the proximal radial nerve was left in proximity to the median. The distal radial nerve could not be identified, and extensive dissection in the distal musculature was not thought advisable. The muscles, subcutaneous tissue, and skin were approximated with interrupted sutures of silk. Two drains were left in the wound. The operative procedure took approximately 7½ hours. A volar, padded, plaster splint was applied in the operating room, and the extremity was elevated beginning in the immediate postoperative period. The radial pulse was present immediately after the anastomosis, and color

Fig. 1. Appearance of a replanted extremity one year after operation. Inverted V-shaped scar is visible. Note foot drop and absence of swelling. Print is reversed as this is a left limb amputation.

Fig. 2. Amputated arm prior to debridement. Clean muscle division and avulsed attenuated nerves are visible.
to debridement. The wound of the amputation was closed with 0000,000 units of intravenous set.

The proximal and distal stumps were joined with sutures and plates. Proximally one centimeter was percutaneous incision made over the olecranon process, which healed slowly. A long, longitudinal, medial incision was made without the use of a proximal tourniquet. The medial antibrachial cutaneous nerve was used as a free graft to bridge a long gap in the ulnar nerve, necessitated by resection of an 11-cm. neuroma. A similar resection of the median nerve was repaired by mobilization and suture of the nerve under some tension. No attempt was made to repair the radial nerve during this lengthy, difficult procedure. Twelve weeks later, the radial nerve was approached by opening the upper end of the longitudinal incision and making a second incision on the lateral surface of the forearm where the distal end of the radial nerve was identified. The proximal neuroma was resected and the 14-cm. gap bridged with a free sural nerve graft. Recovery from both nerve procedures was uncomplicated. Innervation of the distal biceps muscle was evident four months after the second procedure, and innervation of the finger flexors was detected six months after the second procedure. One year after injury, the patient had good shoulder motion and reasonably good elbow motion (Fig. 4). He has weak finger flexion but no wrist or finger extension. There is an imperfect, but protective, level of sensation down to the wrist over the medial portion of the forearm, and there is some sensation in the fingers which is not considered protective. The patient did not wear a cast from the eighth month on and conducted his own physiotherapy, including muscle stimulation, from the eighth month on. He has continued as a college student and lost less than one month of class time after the original hospitalization.

Discussion

Interest in replantation of amputated extremities has existed in experimental laboratories for decades, beginning with the work of Halsted Höpfner, and Carrel. More recent series include those of Lapchinsky, Snyder, MacDonald, and Eiken. The experimental design and techniques employed in these series varied suffi-
ciently to prevent meaningful comparison. It seems clear that replantation of the extremity in the dog can be accomplished successfully in a reasonably high percentage of experiments. The percentage of successful replantation reported in this communication (9 of 12 surviving animals) is as good as that reported in other series including the use of perfusing solutions, Heparin, or microsurgical techniques.

Experimental data with regard to the permissible period of complete circulatory interruption is reasonably consistent. Without perfusion of the extremity or induced hypothermia, microscopic evidence of irreversible muscle damage has been described after six hours of ischemia. The authors' laboratory series indicate that up to six hours of circulatory interruption at room temperature does not preclude a high percentage of extremity survival. Lapchinsky reports extremity survival after 24 hours, using cooling and perfusion of the amputated extremity, and Malt has estimated that the permissible period of replantation using hypothermia and perfusion of the extremity may be up to 15 hours.

The least conclusive of the experimental observations concern long range return of function to the replanted extremity. Lapchinsky reported better results than those described by other authors, including the present series. Inability to provide physiotherapy to the experimental animals and the difficulty in evaluating more than gross functional return leave many important questions unanswered. The most sophisticated studies of functional return are those reported by Eifken.

Successful replantation of a totally amputated extremity in a human was first reported in 1964 by Malt, who describes two successful operations for replantation of severed upper extremities with sufficiently long range follow-up to judge the operations successful from a functional point of view. Very few subsequent cases have been fully reported. Until sufficient experience is recorded, it seems clear that individual, complete case reports are valuable.

Repair of partially amputated extremities and of major vascular injuries has been reported frequently. It seems reasonable to assume that venous drainage in the undivided tissue may have contributed significantly to success in such instances, and strengthens the impression gained from experimental work that venous continuity is critical to successful replantation.

Replantation, of course, a combination of commonly used surgical techniques. The amputated extremity should be cooled by immersion in ice water. The necessity for rapid transport of the patient and the extremity to a center where replantation can be carried out deserves emphasis. The vascular system of the amputated extremity can be easily perfused, using a standard I.V. infusion set. The infusion solution should be Ringer's lactate containing a small amount of Heparin and a relatively non-irritating antibiotic, such as Penicillin. Low molecular weight Dextran appears to have some advantages. It seems important to restore bone continuity initially. The bone should be shortened to permit suture of muscles. Ordinarily, approximately 2½ cm. is adequate for this purpose. The method of bone fixation should provide good stabilization with minimal interference of bone blood supply. Venous continuity should be restored following bone fixation, and this is considered the most critical factor in early survival of the limb. As many large veins as possible should be repaired. The technic of repair is standard, but the use of interrupted, carefully placed sutures of extremely fine material seems important. Arterial anastomosis is next performed using standard technics. Gaps in either vein or artery can be bridged using autologous saphenous vein. Restoration of arterial circulation is followed by impressive bleeding from the distal muscle ends, and at this point transfusion of the patient will almost always be necessary. The method of handling the severed nerves
The replantation of amputated extremities is a valuable procedure as long as it is performed with the utmost care and precision. The initial assessment of the injured limb is crucial, as the condition of the nerve supply will determine the viability of the limb. If the nerves are cleanly severed, careful primary anastomosis, perhaps using an operating microscope, seems indicated. Where injury to the nerve is obvious, repair must be accurate (which is usually the case), and the nerve ends may be left to permit subsequent resection and accurate re-anastomosis. The procedure of choice is the repair of muscles and skin, as this is essential for the success of the surgery.

In the immediate postoperative period, edema is expected. Elevation of the amputated extremity and gentle elastic compression are usually sufficient. The question of fasciotomy has been raised, but in the case reported in the experimental series, this has not been necessary. Edema can be expected to subside slowly, usually after the second week.

The metabolic effects of replantation appear to be similar to those following restoration of circulation to ischemic areas, such as tourniquet shock, release of aortic cross-clamping, etc. Detailed discussion of this subject is beyond the scope of this communication. Shock and renal injury are the most commonly recognized clinical phenomena. The hazard of these complications increases with the duration of ischemia. Cooling of the amputated extremity, recognition and replacement of plasma loss, use of low molecular weight Dextran, and administration of tromethamine have experimental support.

Management of the denervated extremity should include proper protection of the extremity and early institution of physiotherapy designed to prevent contractures and to preserve muscles. The success of replantation depends upon the extent of return of sensation and motor function in the extremity. In most instances, it seems likely that secondary procedures for nerve grafting, or neurolysis, will be necessary. Improvements in the management of peripheral nerve injuries will obviously affect the outcome in replantation procedures.

Conclusion

The current attitude toward surgical replantation should be one of guarded optimism. The long period of rehabilitation, usually involving several hospital admissions, the risk of partially understood systemic effects, and the uncertain end result make careful selection of patients mandatory. Conclusions regarding the value of the procedure and specific indications for attempting it must await further clinical information.

Summary

In a series of dogs the left hind limb was amputated and replanted using standard surgical technics. A high percentage of successful replantation was achieved when circulation was restored within 6 hours after amputation. Long-range return of function was incomplete. In a single clinical experience a right upper extremity was replanted according to the procedure developed in the laboratory. At one year following replantation there has been appreciable but incomplete return of function in the extremity.

Acknowledgment

The replantation patient became a Center-wide project. The assistance, advice, and support of our professional colleagues, particularly the resident staff, nurses, and physiotherapists, too numerous to name individually, are gratefully acknowledged.

References


**Discussion**

Dr. Jesse E. Thompson (Dallas): Some months ago we had the good fortune to hear Dr. Williams discuss this subject in Dallas, and therefore were prepared when shortly thereafter, in August of this year, we were presented with a patient, a 18-year-old man, whose right arm had been severed by the wheel of a train.

My partner, Dr. Don Patman, replanted the arm, and to him goes all the credit for the successful outcome of this case. Dr. George Boswell performed the orthopedic portion of the operation.

Several points in the technic varied a bit from those outlined by Dr. Williams, and I thought these might be of interest. In the first place, a Fogarty embolectomy catheter was used to extract clots from both the distal artery and from the veins. Second, the vascular anastomoses were completed before bone stabilization, since six inches of bone were missing and fixation had to be accomplished by means of a fibular graft. Third, the arterial suture was done first; the distal vasculature was then flushed out and more clots were removed. The artery was re-clamped, and the venous anastomosis was then carried out.

Fourth, a fasciotomy was done in the distal arm, in an effort to improve the chances of survival. And last, stimulating electrodes were implanted in the distal muscles for later physiotherapy.

(Slide) The first slide shows the extensive crushing nature of the wound. That tiny bit of skin had to be divided; the ulnar and median nerves appeared anatomically intact, but were crushed and were functionally divided. All other structures were completely severed. (Slide) This shows the completed arterial and venous anastomoses, the radial and musculocutaneous nerve sutures, and the bone graft. (Slide) This shows the soft tissues being closed. (Slide) The next slide shows the appearance of the arm after healing, following some skin grafting which was required to cover the defects.

(Slide) The next slide shows an X-ray of the bone postoperatively, with shortening of the arm of about one inch. You may think that is callus, but it is not; it is just ground-up bone chips. (Slide) The last slide shows the patient at 3½ months after the accident. His arm has survived successfully, but is still a non-functioning extremity. The functional outcome here, as Dr. Williams has pointed out, will depend upon the return of his nerve and muscle function, and may require further nerve operations, even though the ulnar and median nerves were anatomically intact.

Dr. William E. Price (Closing): We appreciate Dr. Thompson's remarks and congratulate him on the remarkable case of injury described. In the laboratory only on one animal had thrombosis of the vessels at the time replantation was accomplished. Perfusion was carried out in our patient by dripping normal saline containing heparin and penicillin prior to undertaking the anastomoses.