HUMAN ORGAN SUPPORT
AND REPLACEMENT

Transplantation and Artificial Prostheses

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Chapter 18

LIMB REPLANTATION

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Surgical restoration of severed extremities has been successful in a number of patients following complete traumatic amputations. In addition to the obvious value of these operations, it is clear that experience with preservation and replantation of such extremities will furnish important information when (and if) limb homotransplantation becomes feasible. Furthermore, knowledge gained from limb replantations may be useful if effective methods of treating disease, particularly neoplasms, involving extremities and requiring complete vascular isolation are developed.

HISTORICAL CONSIDERATIONS

Since antiquity, man and his physician have been intrigued with the problem of replacement or substitution of parts of the body. The legend of Cosmas and Damian is an example of such interest. Tagliacozzi, in the Sixteenth Century, reported successful restoration of amputated noses. Early reports of small part grafting have been critically reviewed by Gibson. Though it is hardly surprising that there are no believable early reports of successful major limb replantation, it is of interest that the concept of limb replantation is indeed an ancient one.

Modern experimental limb replantation began in 1903 when Hopfner reported three experiments in which dogs' extremities were completely amputated and replanted. The longest survivor lived eleven days, but the extremity was viable at the time of the animal's death. Three years later, Carrel and Guthrie reported leg viability for fifty hours in a replanted dog limb. In 1908, Carrel described a successful dog leg homograft of twenty-two days duration. Interest in experimental replantation per se appeared to lag in the first half of this century and was rarely reported until 1960 when Lapchinsky described sixty-seven experimental limb replantations with sixteen successful procedures. Since 1960, several groups in the United States and abroad have reported experimental limb replantation in dogs. Bunke has studied digital replants in primates. These experiments established the technical feasibility of limb
replantation, delineated some of the problems encountered, and furnished a good deal of data concerning the physiology of limb replantation. Experimental limb replantation is discussed in detail by Nabheth. Studies of many aspects of circulatory physiology as well as the development of methods of bone fixation and peripheral nerve repair have obviously contributed to the techniques of limb replantation.

In view of centuries of interest and the fact that early workers in experimental limb replantation clearly anticipated both limb replantation and limb homotransplantation, it is surprising indeed that more than fifty years elapsed between the initial experimental success and clinical application. Without debating the propriety of making historical judgments from close perspective, it seems certain that the operation performed by Malt and associates on May 23, 1962, is of lasting importance. This operation involved replanting the right upper extremity of a twelve-year-old boy following traumatic amputation below the shoulder. Following this successful procedure, a number of extremity replantations have been performed and will be discussed subsequently.

**SELECTION OF PATIENTS FOR REPLANTATION**

Currently, replantation should be considered after every traumatic amputation involving an upper extremity. In making the decision to attempt replantation a number of factors must be carefully considered, and there are many reasons why a decision not to attempt replantation will be proper. It should also be stated that as experience with limb replantation increases, the indications for attempting it will be altered.

In contrast, replantation of an amputated lower extremity should be performed only in highly selected instances such as loss or impending loss of the opposite leg. Reasons for this include the severe disability associated with an anesthetic lower extremity and the relatively satisfactory function of leg prostheses.

The factors to weigh in selecting patients for upper limb replantation might be considered in four categories.

**The Presence and Severity of Associated Injury**

It is essential that enthusiasm for replanting an amputated extremity does not jeopardize the general care of the patient. The presence or absence of life-threatening injury other than the amputation must be carefully ascertained. Serious injury to the chest, abdomen, or head should probably preclude an attempt to replant an amputated extremity. This is, of course, an individual decision and depends upon the exact nature of the injury, the age and condition of the patient, and the facilities available for care.
Limb Replantation

The Condition of the Amputation Wound

The most favorable type of traumatic amputation is simple severance of the extremity with a clean, sharp instrument. Such an injury is rarely encountered, and most often a judgment must be made regarding the suitability of the wound for replantation. Contraindications include severe injury to the amputated member and massive contamination of the amputation wound. There is some disagreement about the suitability of avulsion-type amputations for replantation. The patient reported by Williams and associates is clearly an example of an avulsion injury, occurring when the extremity was inserted into a high speed water extractor. In this case a satisfactory functional result will be described later. It is probable that the patient described by Rosenkrantz and associates also had an avulsion-type injury. On the other hand, Shaftan mentions several avulsion injuries in which attempts at replantation were unsuccessful. The limitation in avulsion injuries is principally the extensive damage to the peripheral nerves necessitating multiple, long, free nerve grafts. Certainly, if there is evidence of nerve avulsion at the cord level, replantation should not be attempted.

The Time Interval Between Amputation and Replantation

It is obviously important to know the maximum time interval following amputation at which limb replantation can be successfully accomplished. Intravascular clotting, cell viability, and the likelihood of wound infection are time related. Clinical observation and experimental evidence indicate that intravascular clotting in the amputated extremity generally will not occur prior to six hours after amputation. Animal experiments suggest that skeletal muscle becomes irreversibly damaged by ischemia after approximately six hours. Skeletal muscle is the tissue most susceptible to ischemia in the extremity. In amputations distal to important skeletal musculature, a somewhat longer period of time between amputation and replantation may be permissible. Finally, experimental replantation in the laboratory has been shown to be consistently successful when the period of ischemia is limited to six hours or less.49

There are several methods by which the viability of an extremity can be prolonged. The simplest of these is cooling of the extremity by immersion in ice or cold solutions. Preservation of viability by hypothermia was described years ago by Allen and by Brooks and Duncan. The exact limits of safety obtained by cooling the extremity are not known, but Lapchinsky reported successful replantation of a dog limb cooled to 4°C for twenty-eight hours. Perfusion of the vasculature to remove blood should prevent intravascular thrombosis and further prolong the period of viability. Prolonged perfusion with nonoxygenated solutions has no
value. The effectiveness of various perfusion solutions in clearing the circulation has been studied by Mehl. Balanced salt solution containing heparin appears to be the solution of choice at the present time. Both amine buffers and low molecular weight dextran may have additional value but evidence for this is not conclusive. Preservation of the extremity using a pump oxygenator and perfusion has been reported in experiments by Snyder. Hyperbaric oxygenation as a means of preserving extremities has been mentioned by Malt and Reich. The possibilities of chemical preservation of tissues are discussed elsewhere in this symposium.

Successful replantation of a human extremity has been reported up to seven hours after amputation. Theoretically, if the extremity has been cooled, the circulation cleared by perfusion, and the extremity preserved in a hyperbaric atmosphere, an attempt at replantation might be feasible after a considerably longer period of time.

**Individual Facility and Patient Factors**

Limb replantation should not be carried out where the existing facilities are such that the attempt to replant an extremity will jeopardize the care of other patients. This limitation may be in physical facilities or personnel.

The emotional characteristics of the patient are crucial in successful limb replantation. This is extremely difficult to judge in an emergent situation, but if information is available regarding the patient’s motivation, emotional stability, reaction to illness, and so forth, it should be weighed in making a decision to attempt replantation.

The age of the patient is important for several reasons. Salvage of an extremity in a younger person is of relatively great importance. It should also be mentioned that nerve regeneration appears to be more complete in children. Certainly, if the two or three years required for rehabilitation represent a significant portion of life expectancy, the operation should not be attempted.

Finally, consideration should be given to the impact of the replantation on the patient’s existence. Is the expected use of the arm worth two years of daily physiotherapy and several additional surgical procedures? Can the patient continue gainful activity, or, if not, are there resources available for support? In view of the uncertain result of limb replantation, the investment of both time and money by the patient should be considered in making a decision regarding the advisability of an attempt.

**TECHNICAL ASPECTS OF REPLANTATION**

Although it is true that limb replantation involves long-established...
surgical principles and techniques, experience indicates that there is value in preliminary organization and preparation for the performance of the procedure. It is probable that limb replantation is within the scope of every well-trained surgeon. Success in the long-range, however, will be dependent upon the availability of persons trained and interested in various aspects of rehabilitation. Discussion of the technical aspects of replantation might reasonably be divided into the immediate preoperative period, the actual replantation operation, and the immediate post-operative period.

**Preoperative Preparation**

It is assumed that bleeding from the donor site is either minimal, which is surprisingly often true, or has been appropriately controlled by pressure. Methods of preservation of the amputated extremity have been discussed previously. At the scene of the accident, the extremity should be placed in an iced solution, avoiding excessive cooling, e.g. dry ice. When the extremity reaches a facility where perfusion under favorable conditions is possible, intermittent clearing of the vascular system should be carried out. This can be done using sterile cannulae of appropriate size and simple gravity perfusion using intravenous fluids. The criteria for discontinuing the gravity perfusion is the appearance of clear or only slightly blood tinged fluid from the veins. As mentioned previously, the solution of choice appears to be balanced salt solution containing heparin and probably a nonirritating antibiotic such as penicillin. When simple gravity perfusion fails to clear the circulation, the extraction of clots by a balloon catheter may be useful.14,45 Obviously damaged tissue can be removed from the distal stump, but debridement should be delayed until circulation is reestablished. The donor site is prepared by extensive irrigation and careful debridement, and the operation is begun. It should be emphasized that although hemorrhage may have been minimal at the time of injury, reestablishment of circulation is certain to result in significant hemorrhage and plasma loss into the extremity. Blood for transfusion must be available when the replantation is begun.

**Replantation Operation**

Following surgical preparation, copious irrigation of the severed extremity, perfusion of the vasculature, and preparation and debridement of the amputation stump, the actual replantation procedure is begun.

**A. Bone.** In general, it is preferable to stabilize the wound by performing the fracture reduction and fixation as the first step in replantation. The exact method of fracture fixation will depend upon the level and type of bone severance. In amputations proximal to the wrist joint, the
bone must be shortened. In general, 2 to 4 cm of shortening will allow reapproximation of the soft tissues. This shortening may be utilized to produce a favorable oblique osteotomy line. Malt and Harris\textsuperscript{28} have suggested intramedullary bone fixation which has the advantage of being less bulky than plates. Intramedullary fixation was used almost universally in experimental replantation. A theoretical disadvantage of intramedullary fixation is interference with medullary venous drainage. When the fracture is extensively comminuted or is in a location which does not favor intramedullary fixation, the use of plates, screws, and wires may be employed.

B. Blood Vessels. There is temptation to perform the arterial anastomosis initially in limb replantation. The risk of damage to this anastomosis during subsequent bone repair and the necessity for clamping the artery to prevent excessive blood loss while the veins are being repaired dictate against this inclination. In the usual replantation procedure, venous anastomoses are completed after osseous repair and before arterial anastomosis. It is probable that inadequate venous drainage is a more common cause of circulatory failure after replantation than insufficient arterial flow. As many veins as possible should be anastomosed. It is particularly important to prevent rotation deformity and to prevent constricting the anastomoses. Hydrostatic dilatation of both ends of the vein is quite helpful.\textsuperscript{28} Although most reports describe continuous suture anastomosis, in the hands of surgeons not thoroughly familiar with small vessel anastomotic techniques, simple interrupted sutures are less likely to constrict the anastomosis. The suture material itself is a matter of individual choice. Most authors appear to favor 5-0 or 6-0 synthetic fiber sutures. Stapling and coupling devices have been employed and appear to be useful in experienced hands. In amputations at the wrist or hand level, a binocular loupe may aid surgeons familiar with working with this instrument. Experience suggests that down to vessels at the digital level, magnifying devices are not necessary to achieve a high patency rate.

The arterial anastomosis is performed after debriding the arterial ends and is technically easier than the venous anastomosis. The arterial ends may be gently dilated, and the anastomosis performed with either continuous or interrupted sutures. In amputations distal to the elbow, both major arteries should be repaired. When the arterial blood flow is restored, bleeding from the extremity side of the wound is usually profuse, and in amputations through a largely muscular area, bleeding can be torrential. The hemorrhage occurs from sizable vessels which have been severed without hemostasis as well as from a maximally dilated microcirculation. A few minutes of packing may be necessary followed by prolonged and tedious attempts to secure hemostasis. The surgeon should
A. The injury

B. Bone fixation

C. Vein anastomosis

D. Suture soft tissue

Arterial anastomosis

Nerve anastomosis immediate or delayed

Figure 18-1

be prepared to transfuse the patient at the time when vascular cross clamps are released. Hypotension immediately after the release of clamps has been noted in both animals and man. This immediate response may be due to blood and plasma loss into the extremity, a vasodepressor sub-
stance, the return of acidic blood to the circulation, or some combination thereof.\textsuperscript{13,25,32}

C. Nerves. When circulation has been restored and hemostasis secured, a decision must be made regarding surgical management of the nerves. In highly favorable situations when the nerves have been severed sharply in a patient in good general condition, careful definitive nerve anastomoses can be performed at the initial procedure. The nerve ends should be trimmed sharply and fine perineural interrupted sutures employed to approximate the ends. If the surgeon is accustomed to using a binocular loupe, magnification is helpful in accurately aligning fascicle structures. In the majority of instances of limb replantation, definitive primary nerve repair should not be done. If possible, the nerve ends should be identified and sutured together to permit subsequent identification. If this is not possible, fine metallic sutures placed in the nerve ends may be helpful in subsequent identification. Since the extent of peripheral nerve regeneration determines the final outcome of the procedure, the management of the severed nerves should receive most careful consideration. Improvements in the techniques of managing peripheral nerve injuries are surely forthcoming, and a surgeon interested in transplantation must be familiar with such advances.

D. Debridement and Closure. At this point, thorough debridement of nonviable tissue should be carried out. Circulation will have been restored for a sufficiently long period of time to allow identification of avascular areas. Following meticulous debridement, anatomical repair of muscles and tendons is carried out. If adequate coverage of vessels and nerves is not possible due to muscle and skin loss, flap coverage must be instituted. Drainage of the wound is indicated for at least twenty-four hours. Following closure and before discontinuing the procedure, fasciotomy should be considered. Opinions vary regarding the indications for fasciotomy. The general feeling is that this should not be done routinely. Since the extremity is anesthetic, fasciotomy can be carried out at any point in the postoperative period without added anesthesia.

Postoperative Management

Depression of the cardiovascular system, occurring at the time of restoration of the circulation or in the early postoperative period, has been reported both experimentally and clinically.\textsuperscript{13,25,37,44} This phenomenon seems comparable to the tourniquet shock reported by Wilson and Roome\textsuperscript{50} and probably involves three mechanisms—immediate pooling of blood in the distal vasculature, gradual loss of plasma into the injured area, and finally, the release of toxic substance from the extremity into the general circulation.\textsuperscript{13,25} This may simply be acid metabolites, as described by Mehl.\textsuperscript{32}
Awareness of this phenomenon, its prevention and treatment, should prevent its becoming a threatening problem. Intravenous fluids, including blood, should be given in adequate quantities during the procedure, and the addition of sodium bicarbonate or amine buffers should be considered at the time circulation is restored.\textsuperscript{32}

Measures to prevent infection include perfusion of the extremity with a solution containing an antibiotic and administration of antibiotics in large doses intravenously during the early postoperative period. A most important step in the prevention of infection is careful and complete debridement of the wounds.

Edema in the amputated extremity has been reported almost universally and is a consistent experimental finding. The formation of edema has been studied by Eiken and associates\textsuperscript{13} in the experimental animal. Edema formation is most rapid in the early postoperative period, reaching a maximum at forty-eight hours and slowly subsiding thereafter. The importance of edema is twofold. First, the edema represents a significant portion of plasma volume and this must be replaced to prevent shock and its consequences. Secondly, the edema poses a threat to the microcirculation in the extremity.\textsuperscript{20} The management of edema is limited to elevation of the extremity and perhaps to the use of mild pressure dressing. Constricting dressings must be carefully avoided. The extremity must be handled with the care reserved for totally anesthetic tissue. Padded splints and extreme vigilance regarding pressure points are necessary.

Physiotherapy should begin quite early. Probably the initial management should consist only of preservation of joint motion. Galvanic stimulation to denervated muscle should be considered as early as possible. Dynamic splinting after the wounds are healed and the fractures stable may be helpful. The continued assistance of an interested Department of Physical Therapy is invaluable and probably essential to success.

If the nerves have not been primarily repaired, reexploration should be carried out early, preferably within three weeks. Early anastomosis is thought to give better results in terms of nerve regeneration, and it is generally true that exploration is technically easier at three weeks than at six to twelve weeks. At reexploration, neuromas should be resected and nerve continuity restored by primary suture, if possible, or by nerve grafts if primary suture is impossible. The inadequacy of methods of bridging sizable nerve gaps is the greatest single deterrent to limb replantation. As nerve regeneration occurs in the remote postoperative course, orthopedic maneuvers to improve limb function can be considered. Such procedures as joint fusion and muscle and tendon transfers may contribute significantly to the rehabilitation of the patient and the replanted extremity.
CLINICAL EXPERIENCE WITH REPLANTATION

The value of extremity replantation depends upon the degree of functional recovery which can be achieved. In turn, the degree of functional recovery must be compared not only with normal but with currently available prostheses which furnish the only therapeutic alternative to replantation. In making such comparisons, consideration must be given to the risk of the replantation operation and of subsequent surgical procedures and the time involved in hospitalization and physiotherapy. It should be emphasized again that improvements in the technique of replantation and in the function of prostheses will necessitate continual review of results.

A review of the current experience with extremity replantation must form the basis for estimates of the degree of expected functional recovery. The patients reported to date are listed in Table 18-I. These patients all had either complete severance of the extremity or severance with the exception of a small bridge of skin. This arbitrary grouping is simply an attempt to include truly comparable cases. Even so, there is obvious difficulty in making comparisons. The dissimilarity of the wounds, differing levels of amputation, variation in operative and postoperative management, and individual evaluation of results preclude all but general conclusions. The patients listed in Table 18-I undoubtedly do not represent the entire national or international experience with extremity replantation and the table is not presented to establish priority. It may well be that the reported cases represent the more favorable results. From the table it can be seen that there are nine patients with virtually complete extremity amputation and replantation whose status at a minimum of one and one-half years following replantation has been reported. The one and one-half year interval is again arbitrary and a longer interval, perhaps three years, might be more significant. If this time limit were selected, only five results could be evaluated.

Of the nine cases whose functional status is described longer than one and one-half years after replantation, eight results are considered good, that is, the result is considered by the surgeon to be preferable to any currently available prosthesis. One case, Patient number 10, is considered a failure by his surgeon but apparently enjoys a unique and desirable social stature as a result of the replantation and refuses to consider amputation. To illustrate the degree of functional return classified as "good," four patients are described in some detail.

Patient No. 1—The first successful limb replantation in a human was reported by Malt and associates. The patient was a twelve-year-old boy whose right arm was amputated at the shoulder in a train accident. Circulation in the extremity was restored three and one-half hours after injury.
A 14-year-old boy sustained a Girdlestone amputation. To the best of our knowledge, there were no complications. One of the patients, a three-year-old girl, required a replantation. There were 10 reimplants in this series. Of these, one was a failure, and one is currently undergoing a functional test.

**Table 18-1**

<table>
<thead>
<tr>
<th>Age (yr)</th>
<th>Date of Operation</th>
<th>Site of Amputation</th>
<th>Duration of Ischemia</th>
<th>Duration of Follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Malt and Assoc.</td>
<td>12</td>
<td>May, 1963</td>
<td>Rt. shoulder</td>
<td>3% hrs</td>
</tr>
<tr>
<td>2. Shorey and Assoc.</td>
<td>42</td>
<td>Aug., 1962</td>
<td>Rt. 7 cm prox. to wrist</td>
<td>3%</td>
</tr>
<tr>
<td>3. Herbsman and Assoc.</td>
<td>31</td>
<td>Nov., 1962</td>
<td>Left wrist</td>
<td>&lt;5</td>
</tr>
<tr>
<td>4. Ch'en and Assoc.</td>
<td>27</td>
<td>Jan., 1963</td>
<td>Rt. above wrist</td>
<td>4</td>
</tr>
<tr>
<td>5. Malt and McIlhany</td>
<td>44</td>
<td>Sept., 1963</td>
<td>Rt. distal humerus</td>
<td>5</td>
</tr>
<tr>
<td>6. Inoue and Assoc.</td>
<td>26</td>
<td>Oct., 1963</td>
<td>Left wrist</td>
<td>7</td>
</tr>
<tr>
<td>7. Ch'en and Assoc.</td>
<td>23</td>
<td>Nov., 1963</td>
<td>Left midarm</td>
<td>4</td>
</tr>
<tr>
<td>8. Ch'en and Assoc.</td>
<td>26</td>
<td>Dec., 1963</td>
<td>Right midpalm</td>
<td>—</td>
</tr>
<tr>
<td>9. Ts'ui and Assoc.</td>
<td>45</td>
<td>Feb., 1964</td>
<td>Right axilla</td>
<td>5%</td>
</tr>
<tr>
<td>10. Shafton and Assoc.</td>
<td>28</td>
<td>July, 1964</td>
<td>Rt. upper arm</td>
<td>—</td>
</tr>
<tr>
<td>11. Williams and Assoc.</td>
<td>20</td>
<td>Nov., 1964</td>
<td>Rt. midhumerus</td>
<td>5</td>
</tr>
<tr>
<td>12. Rosenkrantz and Assoc.</td>
<td>20 mo</td>
<td>Apr., 1965</td>
<td>Left axilla</td>
<td>5</td>
</tr>
<tr>
<td>13. Bora and DeSantis</td>
<td>57</td>
<td>Aug., 1965</td>
<td>Right wrist</td>
<td>—</td>
</tr>
<tr>
<td>14. Thompson</td>
<td>19</td>
<td>Sept., 1965</td>
<td>Rt. midhumerus</td>
<td>6</td>
</tr>
<tr>
<td>15. Malt</td>
<td>26</td>
<td>Feb., 1967</td>
<td>Left wrist</td>
<td>—</td>
</tr>
</tbody>
</table>
At subsequent operations, repair of major nerves including nerve autografts was performed. Elbow flexion was strengthened by reversing the direction of the extensor carpi radialis longus and activating this tendon with the pectoralis major. Failure of radial nerve regeneration necessitated wrist fusion. The functional status of the extremity at six years and three months has been described by Harris and Malt. There is protective sensation in the hand with perception of a 150 mg hair over much of the palmar surface. Two point discrimination is 1.5 cm in some areas and less satisfactory in other areas of the hand. The primary motor deficit is due to failure of radial nerve regeneration. There is good finger and thumb flexion and the grasp is strong. There is no independent finger motion and no intrinsic function with the exception of the opponens. The patient uses the arm extensively as an assisting arm. His occupation involves waxing floors with a floor polisher which he is able to control using the replanted arm. The arm is in active use and is clearly more valuable than any known prosthesis. Pain and pain syndromes have not been a problem in this patient.

Patient No. 3—A thirty-one-year-old male was struck across the left wrist with a meat cleaver producing amputation of the hand with the exception of a 4 cm bridge of skin without subcutaneous tissue. Replantation was carried out by fixation of the bone, arterial, and then venous anastomoses. Total operating time was five hours. Repair of nerves and tendons was performed at three and one-half weeks. Additional tendon repair procedures were ultimately performed. At sixty-seven months after replantation, the patient has sensation to pinprick and light touch in the hand. Two-point discrimination in the fingertips is 21 to 35 mm but is described as normal in the palm. The grasp is good. Poor thumb-index apposition is present but thought to be amenable to a relatively minor surgical procedure. The patient uses the hand in daily activities and it is considered preferable to a prosthesis.

Patient No. 11—A twenty-two-year-old college student sustained amputation of the right arm at midhumerus when the patient attempted to remove clothing from an operating water extractor. The patient was transported seventy miles, and the circulation was restored five hours after injury. Two subsequent procedures were performed for nerve repair, and free nerve autografting was necessary. The patient lost a total of one semester of college. Forty-five months after the replantation, the patient has protective sensation in the hand. Sensory return is incomplete and lack of position sense and accurate localization limits the usefulness of the extremity. Muscle strength in the shoulder and elbow is excellent. There is good wrist flexion, but wrist and finger extension are weak. There is little individual finger flexion, but the grasp is relatively strong. Intrinsic
Limb Replantation

An analysis of the failures in limb replantation would obviously be helpful. It is not surprising that such cases are not often reported, and certainly the few reports represent only a small portion of the total experience. A total of thirteen failures is known to the authors.\(^5,19,23,35,44,48,51\) Often, details of failure are not known. In a general way, the causes of failure might be discussed in the following categories:

1. **Circulatory:** Inability to establish or maintain circulation is an obvious cause of failure in replantation. Early after operation, such failure is usually a result of technical difficulty with vascular anastomoses. The importance of adequate venous drainage is again emphasized. Probably, many early circulatory failures in human replantation are due to the severity of the soft tissue and vascular damage. Edema in the extremity poses a threat to circulation in the first few days after replantation. Experimentally, however, gross failure of the circulation after the first few hours is quite uncommon.\(^48\) Elevation of the extremity and perhaps the use of low molecular weight dextran may be of value in the early postoperative period. Experimental and clinical evidence reported to date indicates that heparin should not be given as a systemic anticoagulant after replantation.\(^27\)

2. **Infection:** Infection is the most common cause of early failure after limb replantation. The numerous factors favoring the development of in-
fection in an inevitably contaminated amputation wound are obvious. The methods utilized to prevent and treat infection have been outlined previously and follow general surgical principles.

3. Pain Syndromes: An interesting feature of early clinical reports of limb replantation procedures is that troublesome pain syndromes were not mentioned. A patient in whom severe pain necessitated reamputation after replantation was reported by Paletta.\textsuperscript{46} Pain syndromes following peripheral nerve injury constitute a particularly complex problem which certainly is related to motivation, secondary gain, and many other psychological and social factors. In this regard, it should be recognized that the long convalescence following limb replantation is a severe emotional stress requiring unusual courage. Continued support from physicians, physiotherapists, and others is critical in most instances.

4. Failure of Nerve Regeneration: Failure to achieve a functional extremity after a reasonable period of time and after exhausting currently known reconstructive procedures constitutes an indication for amputation.

CONCLUSIONS

Replantation of amputated extremities with recovery of a level of function exceeding that of available prostheses has been described in a number of patients. The number of cases reported is too small to permit sweeping conclusions regarding the value of the procedure or the detailed indications for its performance. Experimental limb replantation and the clinical experiences described are of obvious relevance to the field of transplantation.

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