

Upper Extremity Replantation

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Introduction

Replantation is the reattachment of a part that has been completely severed from the body. This is to be distinguished from revascularization where the limb has been incompletely amputated and a portion of the tissue remains in continuity. In this situation, venous and/or lymphatic drainage will frequently exist across the wound (Figure 1A and 1B).

In both settings, vascular repair is necessary to prevent necrosis of the injured part. However, replantation generally involves greater difficulty and a lower viability rate due to the lack of all outflow from the injured part.

History

Replantation surgery has been performed successfully for just over 30 years. Although it was attempted experimentally at the turn of the century, it required the development of appropriate techniques and instrumentation in order to bring about clinical success. The operating microscope was introduced in 1921 by Nylen for otologic surgery and was only mass produced by Zeiss in 1953.¹ Jacobson and Suarez, in 1960,² introduced the type of operating microscope commonly used today.

This involved improved focus, magnification, and motion in multiple planes. The first successful reattachment of a completely amputated human limb, was performed on a 12-year-old boy by a surgical team led by Ronald Malt, in Boston, in 1962.³ Successful digital replantation was reported in rhesus monkeys in 1965.⁴ In the same year, successful digital vessel anastomosis was reported in a devascularized thumb.⁵ The first successful replantation of a completely severed digit was reported in 1968 by Komatsu and Tamai of Japan.⁶

During the 1970's, replantation centers and microsurgical laboratories were developed, and began critically analyzing their results. By the 1980's the techniques and indications for replantation were refined. During this time, the tendency to delay nerve and tendon repairs for several months after skeletal

stabilization and restoration of vascular flow was abandoned. This led to the current technique of all structures being repaired at the time of replantation.

Patient Selection

Each individual amputation must be addressed by the surgeon and patient for the appropriateness of replantation. With today's techniques, many amputated parts can be salvaged, however this in itself does not equate to a "success". This is because certain replanted parts function poorly, and may lead to more frustration and disability than simply having a well functioning amputation stump.

Replantation is generally indicated in the following amputations:

1. Multiple digits;
2. Thumb;
3. Hand amputations through the palm or carpus;
4. Wrist or forearm;
5. At or proximal to the elbow when there is a clean-cut guillotine-like amputation;
6. Individual digits distal to the insertion of the flexor digitorum superficialis on the middle phalanx;
7. Amputations in a child (Figure 2A, 2B, 2C).

Age alone is not a contraindication to replantation. Replantations have been reported in patients from a few weeks old to over 80 years old.^{7,8} However, the results in older patients are worse, particularly with regard to restoration of sensibility, strength, and coordination. In light of this, replantation proximal to the tendinous portion of the forearm may not be indicated in older patients.^{9,10,11} A history of medical illness must also be considered. Coexisting vascular disease, cigarette smoking and diabetes mellitus do result in a higher failure rate but are not absolute contraindications to replantation.

Chronic diseases such as coronary artery disease, malignancy, renal disease and pulmonary disease may entail too high an anesthetic risk to pursue replantation which can last from three hours in a simple single digit amputation to over 24 hours in multiple digit amputations. Patients with rheumatoid arthritis, lupus erythematosus, other collagen vascular diseases and significant atherosclerosis also have diminished

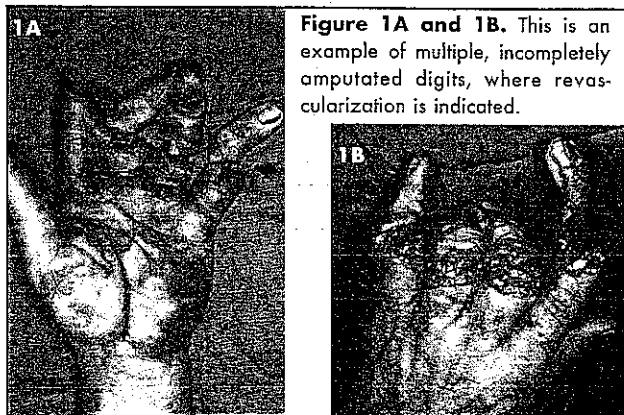


Figure 1A and 1B. This is an example of multiple, incompletely amputated digits, where revascularization is indicated.

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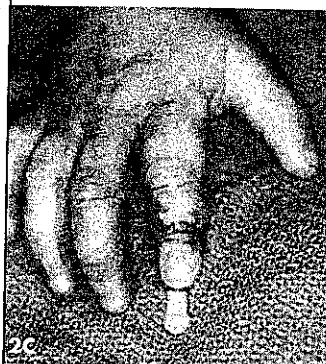
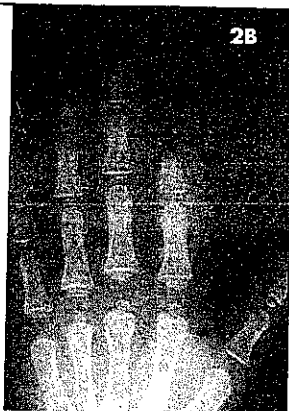


Figure 2A. This index finger amputation is indicated for replantation for two reasons. The patient is a two and a half-year-old child, and the amputation is distal to the insertion of the flexor digitorum superficialis.

Figure 2B. This x-ray reveals the level of the amputation. The flexor digitorum superficialis inserts into the base of the middle phalanx.

Figure 2C. The replantation was performed successfully.

likelihood of success. Patients with psychiatric illnesses must be approached cautiously. If the amputation is an act of self-mutilation, replantation has a high failure rate. If the amputations occur as a true accident, the chances are more favorable.¹

The level of a digital amputation is an important consideration. In general, in this country, a single finger amputation distal to the distal interphalangeal joint is not considered for replantation. However, in other societies, particularly in Asia, replantations of a single finger even distal to the eponychial fold (nail fold) is considered appropriate.¹² Currently there are several authorities in this country recommending microsurgical replantation for finger tip amputations traditionally treated with primary closure. Due to the importance of the thumb, it is considered more strongly for more distal levels of amputation, even when through the nail. This is debated by some authorities who found no improvement in the function of thumbs replanted at the interphalangeal joint level compared with similar injuries treated with wound closure alone. However, most centers recommend preserving as much length of the thumb as possible.^{13, 14}

Relative contraindications to replantation are:

1. Amputations at multiple levels;
2. Mangled parts (Figure 3A, 3B, 3C);
3. Psychiatric illness;
4. Patients in whom serious illness or disease coexist;
5. Individual finger amputations in zone two proximal to the FDS insertion;

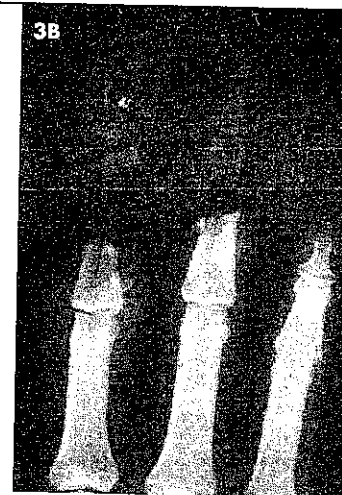


Figure 3A. This injury can be considered for replantation due to multiple digits being involved.

Figure 3B. The amputations through the middle phalanges are appropriate for replantation. There should be concern over the comminution of the distal phalanx of the index finger.

Figure 3C. Examination of the amputated parts themselves reveal that they are not appropriate for replantation. The parts are mangled with evidence of crush injury and ecchymosis all the way to the tips.

6. Amputation with prolonged ischemia time; <
7. Wounds with extensive soil contamination, especially from agricultural injuries;
8. Ring avulsion amputations¹⁵ (Figure 4A and 4B).

Replantation is not recommended when warm ischemia time has exceeded 12 hours for a digit or six hours for a proximal amputation. The digit can survive longer because of the absence of muscle within the part. Cooling of the amputated part can prolong its survival. However, replantation is not recommended when cold ischemic time exceeds 24 hours for a digit amputation or 12 hours for a proximal amputation.¹⁵

Emergency Management

The patient with an amputation has an open fracture. Tetanus status should be verified, and intravenous antibiotics should be provided. The stump is examined and covered with a clean dressing. X-rays should then be obtained in two planes of both the stump and the amputated part. (Figure 5) If there is any possibility of replantation, the surgical team should be contacted immediately as well as the appropriate operating facility and anesthesia services.

There are two equally good methods of preserving the body part.¹⁶ The goal is to preserve the amputated part at a tempera-



Figure 4A. This patient had rings on her ring and small fingers causing an avulsion amputation of the ring finger and venous congestion of her small finger.

Figure 4B. The amputated, de-gloved ring finger included the entire length of the flexor digitorum profundus tendon. It

was not appropriate for replantation. The small finger was salvaged with vein grafting.

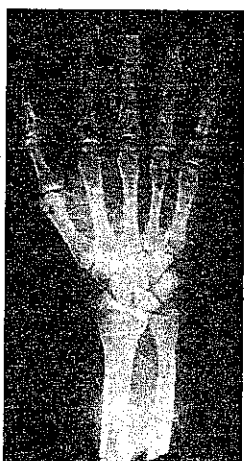


Figure 5. This x-ray of an amputation through a forearm provides information necessary for planning of bone fixation. This was successfully replanted.

ture of four degrees Celsius. Some centers accomplish this by placing the part in a saline filled plastic bag that is secured tightly and placed in a large container filled with crushed ice. I prefer the part to be wrapped in a moist gauze placed in a sealed bag and then placed in an ice slurry.^{17,18} Using both methods, the ice itself should not touch the hand. If the amputated part is frozen or placed in an unphysiologic solution such as formaldehyde or allowed to dry, the chance of a successful replantation is exceedingly low.¹ Dry ice should not be used due to the propensity for freezing the part.

Operative Technique

Entry into the operating room is done as soon as possible. Two surgical teams are preferable. The amputated part can generally be brought into the operating room first. It is meticulously cleaned and then dissected by the first surgical team. The nerves and vessels to be used for anastomosis are identified and tagged. It is at this point that the vessels are examined to insure that a replantation is an option. The extensor and flexor tendons are also prepared. The bone is fixed with hardware that will be used to secure it to its original site. In the digits, this usually involves K-wires.

When the patient is brought into the operating room, general or regional anesthesia is preferred. Often a regional anesthesia is added to a general anesthetic to enhance peripheral blood flow to the injured limb. The patient is also kept warm. At this point, the stump is dissected in a similar fashion with the vessels, nerves and tendons tagged. During this time the amputated part is kept cool on the operating room table. Once

both sites are ready for repair, the bone is generally shortened and fixed. There are varied fixation techniques depending on the level of the amputation. In general, the most rapid technique is selected that will provide for a secure fixation. The tendons are then repaired with the extensor side generally preceding the flexor side. Microvascular anastomosis is then performed. Many authorities recommend repairing the veins first and then the artery followed by repair of the nerves. I prefer to anastomose the arteries and then the veins. At times, establishing arterial inflow will make vein identification easier as they fill with blood. Finally, skin coverage is obtained. Wound closure must be tension free and skin grafting may be required in more proximal amputations.

In major limb replantation, arterial repair is performed prior to venous repair to diminish myonecrosis and clear the part of noxious catabolites that would otherwise be entered into the patient's circulatory system. In this setting as well, prior to replantation, extensive debridement of necrotic appearing muscles is required and extensive fasciotomies are always indicated.

The improved success rate of replantations is due to the refinement of both patient selection and the technique of microvascular anastomosis. The key points during the anastomosis are to frequently irrigate the vessel lumens with diluted heparin solution, minimally strip the adventitia, meticulously handle the vessels both proximally and distally, use non absorbable interrupted suture material of the correct size, and use vein grafts when needed. Currently there is an alternative to suture microvascular anastomosis, the mechanical coupling of vessels using 2 rings incorporating small pins. This is somewhat more limited in its applicability, but can be used for arteries and veins with an external diameter ranging from 0.8 to 2.8 mm¹⁹ is time saving when vein grafts are utilized to bridge arterial gaps. However, it is difficult to use in finger replantations where there is limited exposure of the vessels.

In multiple digit amputations, a heterotopic replantation may be selected. For example, in a combined thumb and index finger amputation; the index part can be replanted to the thumb, if the thumb part cannot be salvaged. The thumb's function is preferentially restored due to its greater importance.

Postoperative Care

The postoperative care begins in the operating room where anticoagulation is usually initiated with either Dextran or Heparin. A large bulky dressing is placed. Only the fingertip is exposed in digit replantations. There should be no pressure on the region of anastomosis, be this in the finger or arm. There should also be no motion permitted in this region. In general, the hand is elevated once the procedure is completed unless arterial inflow is diminished. Although anticoagulation has never been shown to improve the viability of replanted parts, most authorities recommend Dextran or Heparin for two to seven days combined with aspirin for 10-14 days following

surgery. A sedative such as Chlorpromazine is commonly added. This is to reduce vasospasm related to emotional distress. It is also essential to minimize pain, and the spasm this can induce, by using appropriate narcotic analgesics. The patient abstains from smoking and caffeine products. The room is kept warm and visitors kept to an appropriate level where the patient remains comfortable.

Skin color, turgor, and temperature are carefully monitored. This can be done clinically or can be supplemented with pulse oximetry or a temperature probe. A drop in temperature below 30 degrees Celsius, or of 2 to 3 degrees below a normal digit is considered a sign of circulatory compromise. The compromised digit will eventually demonstrate poor perfusion clinically, but this may lag behind the temperature changes. The first dressing is not changed for 10 days to lessen the risk of vasospasm. Mobilization of the replanted part is delayed, in general, for at least one month.

A reattached part that appears to be in jeopardy should be addressed immediately. In general, the first step is to remove the dressing, as it may be constricting the circulation to the replanted part.

Removing the dressing may entail pain and induce vasospasm, therefore it is usually done in the operating room. This is an appropriate time to perform a regional block to relieve vasospasm. These maneuvers may restore excellent circulation. An intravenous bolus of Heparin can also be considered. If these more simple maneuvers do not correct the compromise, consideration can be given to reexploration. Reexploration is seldom beneficial if performed over two days following the replantation or after six hours of inadequate perfusion. However, when performed expediently, re-exploration can lead to a 50% salvage rate.²⁰

The usual cause of a failed digit replantation is venous congestion. This may not be able to be improved upon surgically, and consideration can be given to medical-grade leeches (*Hirudo medicinalis*). These can be effective in relieving venous congestion, both by the actual sucking of venous blood trapped in the replanted digit as well as by instilling an anticoagulant, hirudin, present in its saliva.^{21,22} It is reported by some to have a greater than 50% salvage rate for the replanted digit with venous congestion.^{23,24}

In major limb replantation, it is a good idea to reexamine the limb in the operating room two to three days following the initial surgery to evaluate the condition of the involved muscles. This is due to the higher likelihood of necrotic tissue being present, requiring further debridement.

Outcomes

The average survival rate of digital replantations is 80%. It has been cited as high as 94%;^{10,18,25-29} satisfactory function, however, is found in a smaller percentage. When comparing patients with replantations to those with revision amputations

at similar levels, satisfactory results were reported in 60 to nearly 80%.^{9,11,30-36}

Active range of motion is generally about 50% of normal for amputations ranging from the finger to the entire hand. Cold intolerance is a near universal problem, but subsides about two years following the surgery.^{34,37} Most patients are satisfied, and the cosmetic appearance is preferable to a prosthesis in almost all cases. Recovery of sensation and nerve function is dependent on the injury and patient condition; but in general, neural recovery is comparable to that of repair of an isolated severed peripheral nerve.¹⁵ The best results are obtained in young patients with clean, guillotine-like amputations through the thumb, wrist, distal forearm, or finger distal to the insertion of the flexor digitorum superficialis.

The development of the field of replantation, and its progress over the past 30 years has been remarkable. Further improvements may occur with the development of new antithrombotic agents to be utilized during reattachment and medications to enhance neurovascularization in the postoperative period.

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