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Upper limb replantation

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Abstract

Since the first successful salvage of an amputated finger using microsurgical anastomoses in 1965, replantation has been widely used in these decades and is now firmly established as a viable treatment option in traumatic limb amputation. The current concepts of replantation surgery for upper limb amputation are discussed in this review article in terms of history of replantation, present indications for the procedure, pre-theater care, technical refinements, postoperative management and functional outcome. In this article, we demonstrated that the advent of microsurgery has led to replantation of almost every amputated part of the upper limb possible. Replantation of digits and the hand can restore not only circulation but also function and cosmetic appearance. However, major amputations remain a challenge and the functional outcome is often disappointing, albeit the success rate of replantation exceeds 80%. Proper patient selection, adequate pre-theater preservation, good operative skill and postoperative care, as well as tight cooperation among the patient, the surgeon, and the rehabilitation therapist will help to achieve a better final functional outcome.

Keywords

Replantation, traumatic upper limb amputation, microsurgery

History of replantation

The history of limb replantation is extremely interesting. The earliest replantation work was published by Hopfner in 1903 (Chen, 1997). He reported experimental autoreplantations of the hind limbs of dogs with survival from 1 to 9 days. Carrel and Guthrie (1906) described several attempts at replantation and transplantation of limbs as part of their pioneering work in vascular surgical technique. Reichert (1931) reported the results of 52 replantations of dog legs with primary vascular anastomoses with patency assessed by angiography and Hall (1944) speculated on the use of operative techniques for upper extremity replantation. Some authors, including Lapchinsky (1960), Jacobson and Suarez (1960), and Snyder et al. (1960), published their work on microvascular surgery; the replantation of limbs in experimental animals was performed throughout the world and quickly led to further

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clinical applications. In 1962, Malt and McKhann successfully performed the first extremity replantation on a 12-year-old boy whose right arm was amputated in a train accident (Malt et al., 1964). Kleinert et al. (1963) performed the first clinical microvascular anastomoses on the digital arteries of an amputated thumb. In 1965, Kamatsu and Tamai performed the first successful replantation, using microsurgical anastomoses, of a completely amputated digit (Kamatsu and Tamai 1968). In 1973, 10 surgeons from the United States and Canada visited China on a replantation mission, which resulted in a large number of operations and a high success rate for those replantations (Buncke 1973). As the microsurgical techniques improved and more experience was gained, the strategies for replantation surgery became clearer, operative techniques were more standardized, and survival became more predictable. Today, replantation surgery has become a standard approach to upper extremity amputations throughout the world. By means of well-established protocols for postoperative physical therapy, the functional results often make replantation more satisfactory than a prosthesis. However, for patients with mutilating amputation injuries to the upper extremity, replantation with a functional outcome is still impossible. In these situations, hand transplantation or, perhaps, functional prostheses will be a possibility for replacing replantation in the future.

Patient selection

General guidance for patient selection for replantation is helpful in predicting the eventual results. Moreover, the general medical condition of the patient remains an essential initial consideration for microsurgical replantation. Cardiac disease, poorly controlled diabetes, arteriosclerosis, extensive cigarette smoking history, and altered psychological status are contraindications for replantation (Weiland and Raskin 1990). Although replantation produces superior functional results compared with amputation and a prosthesis (Graham et al., 1998) whether or not the replantation should be attempted is clearly dependent on the following factors, including the type and mechanism of injury, the level of the amputation, ischemia time, and the health status of the patient. Acceptable indications for replantation with upper limb amputations are as follows: (1) amputation of the thumb or multiple fingers, (2) amputation of the hand, (3) major amputation distal to the glenohumeral joint, and (4) individual amputations of fingers distal to the insertion of the flexor digitorum superficialis (FDS) tendon. Although single digit amputation has been deemed a relative contraindication for replantation in the clinical setting, it is very difficult to persuade a patient to refuse a replantation even if a poor functional outcome is anticipated. Therefore, individualization may be the optimum philosophy in replantation surgery. This means that the replantation opportunity appears only once for each severed part, and the decision to discard an amputated part must be individualized and not made to fit a rigid set of rules. In addition, from the functional point of view, the ability to restore circulation is not, in itself, a reason to conduct replantation; the primary goal should be useful functioning of the replanted part. The generally accepted indications and contraindications for upper limb replantation are listed in Table 1.

Pre-theatre care

The mechanism of injury leading to a completely avulsed or amputated limb may be sufficiently severe for advanced life support and trauma guidelines to be implemented (Lloyd et al., 2005). Because individuals with amputated extremities have often lost large amounts of blood prior to reaching the replantation centre, the first priority for pre-theatre management is resuscitation of the patient with circulatory support using intravenous fluids. When the patient has been stabilized and tetanus status determined, wound cultures should be obtained after initial debridement and irrigation. This should be followed by the administration

Table 1. Indications and contraindications for upper limb replantation.

Indications	Contraindications
1. The thumb	1. Concomitant life-threatening injury
2. All amputations in children	2. Multiple segmental injuries in the amputated part
3. Multiple digits	3. Extremely severe crush or avulsion
4. The palm, wrist, and distal forearm levels	4. Extremely contamination, as in some farm injuries
	5. Prior surgery or injury to the extremity that precludes replantation
	6. Precluding systemic illness
	7. Extremely prolonged warm ischemia
	8. Psychical problem

of intravenous antibiotics effective against *Streptococcus*, *Staphylococcus aureus*, and *Clostridium perfringens* (Lloyd et al., 2005). Baseline hematological and biochemical studies and several units of cross-matched blood should be requested. A detailed history taken from witnesses should also be obtained.

Amputations of the upper extremity can be divided into major or minor categories. Major upper limb amputations are those at, or proximal to, the level of the wrist, and minor amputations are referred to as those distal to the wrist. It should be remembered that muscle does not tolerate ischemia well; therefore ways to minimize injury caused by ischemic insult, especially to the proximal muscle bulk, are always a priority for replantation surgery. Proper transportation and preservation of the amputated part is mandatory and is one of the many critical components of successful replantation. Cooling the part protects the tissue from the detrimental effects of warm ischemia. The amputated limb should be laid on a sterile towel and photographed to allow the part to be seen by other medical stuff without re-exposing it. Any fragments of tissue should be retained since they may provide tissue for skin, bone, vessel, or nerve grafting. The limb should be checked meticulously. The amputated limb should be wrapped in sterile gauze, moistened in normal saline, and placed within an insulated box containing crushed ice and water; the proximal stump should be gently wrapped in an elastic bandage. It is obvious that the container with the amputated segment must accompany the patient at all times. Remember that any fragments of the amputated part not used for replantation can be extremely valuable for future reconstruction of a limb, because such parts may be used as sources of nerve, tendon, or skin tissue. On examination, deformities of the limb often suggest underlying fractures of the bone. Radiographic evaluations of both the amputated part and the involved upper extremity should be performed to determine the extent of skeletal damage.

Operative technique

Generally, for the replantation of 1 or 2 fingers, 1 surgical team is adequate, especially considering that the duration of surgery must be within tolerable ischemic time limits and that operative space is limited. However, for proximal upper limb or multiple digit replantations, the use of 2, or even 3, surgical teams is recommended. The first team assesses and prepares for surgery. The second or third team then takes the amputated part to the operating room and cleans it and identifies vessels, nerves, and tendons. It always has to be remembered that 'time is muscle,' and all efforts during the replantation procedure should be planned to reduce the detrimental effects of the ischemia to the muscle.

When the replant is proximal, with a large volume of muscle tissue, a warm ischemia time of 4 to 6 h is the upper limit to prevent extensive reperfusion injury and complete loss of the limb due to vascular leakage, edema, and subsequent tissue necrosis. To shorten the ischemia time, temporary arterial shunting via a Sundt shunt, vascular shunting using the femoral artery, or even cross-limb vascular shunting, has been recommended in difficult major limb replantations (Davins et al., 2007; Lee et al., 2002, 2009, 2011; Nunley et al., 1981; Wei et al., 2010). In our experience, a Nelaton tube is more convenient and valuable for providing a temporary shunt to alleviate the ischemic injury, albeit that the occlusion of this tube will occur after approximately 30 min. It should be noted that massive blood loss from the venous return is expected during the shunting; hence, blood transfusion is generally required and should be prepared for in advance. The surgical procedures of different levels of amputation are described as follows:

Digits

Some authors propose that, in order to shorten the ischemic time, the sequence of the replantation procedure is as follows: bone shortening and stabilization, extensor and flexor tendon repair, arterial anastomoses, venous anastomoses, nerve coaptation, and skin coverage (Soucacos et al., 2001). We prefer, however, the sequence of procedures as follows: bone shortening and stabilization, flexor tendon repair, arterial anastomoses, nerve coaptation, extensor tendon repair, venous anastomoses, and skin coverage. The reason for this is to decrease the number of positional changes of the hand during the replantation. A positional change under the microscope, with subsequent adjustment and focusing, is quite time-consuming. On the volar side, the repair of the flexor tendon, the microanastomoses of both the digital arteries and nerves, and even the skin closure can be performed at the same time. Then the repair of the extensor tendon and microanastomoses of veins can be performed on the dorsal side of the finger. We have found that this sequence can lessen the operative time and improve the comfort of the surgeon during the replantation. Generally, it is possible to complete a one-finger replantation within 4 h. Similarly, for an amputation of multiple digits, we prefer to perform the replantation of all digits with the hand in the same position, repairing the same structures one-by-one, and not replanting the digits one-by-one. With this method, we have reported a successful replantation of all 10 digits on both hands of 1 patient with 3 teams (6 doctors) working simultaneously. The total operating time was 12 h, with the ischemia time for each finger ranging from 5 to 9 h (Kueh et al., 2009).

Initially, while the tourniquet is inflated, midlateral incisions allow broad exposure of the digital vessels and nerves. Digital arteries and nerves are dissected at the palmar side of incisions. Bone shortening is sometimes required to minimize tension during the repair of arteries, veins, and nerves. In addition, anatomic reduction and internal fixation of the amputated part, using miniplates or Kirschner wires with interosseous wires, eventually produces better function (Waikakul et al., 2000). Subsequently, both flexor tendons are repaired by the Kessler technique. In the case of avulsed tendons, primary tendon transfers may need to be performed.

Arterial anastomoses should be performed only on normal intima without tension. In the case of avulsion injuries, significant intimal injury between the proximal and distal ends of the vessels will result in an arterial gap that precludes vessel repair without tension; therefore, a vein graft is indicated. In this situation, vein grafts could be obtained from the volar aspect of the forearm. If vasospasm is encountered, we prefer to use warm normal saline-rinsed wet gauze coverage, spraying with a 2% xylocaine solution, and a continuous intravenous infusion of prostaglandin E1 solution. Caution should be taken to avoid too low a core temperature and the blood pressure of the patient should be supported to avoid vasospasm. In general, the arterial anastomosis is performed in an interrupted fashion using 10-0 sutures for adults or 11-0 sutures for children.

The digital nerves are repaired epineurally in an interrupted fashion using 10-0 sutures. In the case of an avulsion injury with digital nerve defect, immediate nerve grafting is possible with grafts taken from the medial antebrachial cutaneous nerve or from non-salvageable digits. In some cases of amputation distal to the distal interphalangeal (DIP) joint, nerve suturing is not possible because of the anatomic location of the nerve trifurcation.

The hand is then turned to expose the dorsum of the finger in the operative field. The extensor tendon is easy to find and seldom retracts from the wound margin. Then the candidate veins in the dorsum are identified and isolated in the subdermal layer of dorsal skin flaps. After releasing the tourniquet, 2 or 3 of the largest veins exhibiting the strongest back flow will be repaired. Once a vein graft is indicated, the vein grafts may be obtained, under microscopic magnification, from the volar aspect of the wrist or distal forearm. These locations are used because of the appropriateness of the vein sizes.

It is perhaps the most technically demanding part of the replantation to identify and anastomose the suitable veins when the amputation level is just distal to the DIP joint. In the event of fingertip replantation, where the amputation level is located at, or around, the nailfold level, it is difficult to perform the venous anastomosis because of the tiny size of the veins. Some authors have suggested that the use of medical leeches to lessen the venous congestion is helpful (Smoot et al., 1990). However, significant blood loss could occur and prophylaxis against *Aeromonas hydrophila* infection should be instituted when leeches are used. Most importantly, medical leeches are not available in Asian and in some other countries. To drain the returned venous blood, in the situation where there is no suitable vein available for microsurgical fingertip replantation, we introduced a subdermal pocket procedure (Figure 1(a) to (d)) to overcome this problem and have experienced a high success rate (Lin et al., 2004).

Hand

In addition to the forearm receiving the replant (Figure 2(a) to (d)), 1 lower extremity should be prepared for potential vein grafting, if required (Cooney and Wood, 1992). Debridement of devitalized tissue, foreign bodies, or infectious material should be performed with care to preserve potentially viable tissue. After accurate reduction, bone stabilization is performed using 2 or 3 Kirschner wires. Familiarity with the anatomy around the wrist, especially the arrangement of tendons, is the key to performing a successful replantation. Although some authors suggest removal of the FDS tendons of the digits to avoid tendon adhesion between it and the flexor digitorum profundus (FDP) tendons (Hoang, 2006), we prefer to repair all the tendons and simultaneously release the flexor retinaculum ligament, overlying the carpal tunnel, to prevent adhesion and tightness within the tunnel. Initially, all the tendons are repaired, as possible. Both the radial and ulnar arteries and 4 or 5 of the largest dorsal veins are anastomosed in interrupted fashion using 9-0 or 10-0 sutures. In patients with crush-avulsion amputations of the hand, widespread use of vein grafts may result in a high replantation success rate with the physiological length of the upper limb being preserved (Mollski, 2007). The median and ulnar nerves are repaired primarily using an epineural technique with 9-0 sutures. If possible, the superficial branches of the radial nerves should be repaired to prevent the formation of painful neuromas, which are quite bothersome to the patient. The final step is skin closure in a tension-free fashion. If a complete tension-free skin closure cannot be achieved, it should be ensured that all the vital tissues are covered by a viable skin flap. The remaining skin defect may be repaired in a secondary surgery after survival of the replant is assured. If required, an immediate split-thickness skin graft may be used to cover the

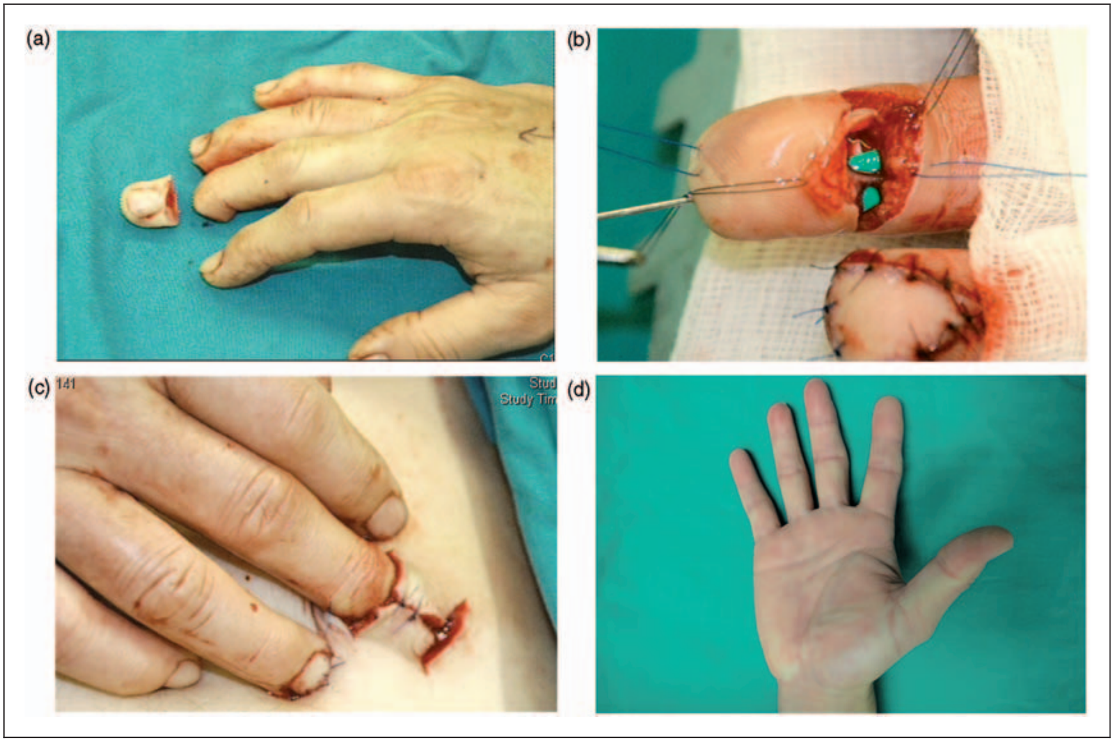

Figure 1. (a) Complete amputation at the distal phalanx of the right long finger. (b) The digital artery of the amputated fingertip was repaired. (c) In the situation with no suitable veins for repair, a subdermal pocket procedure was performed at the left lower abdomen for drainage of the returned venous blood. (d) The amputated part was totally healed with good function and cosmetic appearance at the 6-month follow-up.

vein graft. In instances of prolonged ischemic time, a fasciotomy to prevent compartment syndrome and preserve the small intrinsic muscles is mandatory. The wound is then packed with a soft dressing and a short arm splint is applied for immobilization.

Forearm and arm

The muscle mass of an amputated limb, as well as the recipient stump (Figures 3(a) to (d) and 4(a) to (d)), requires meticulous debridement and revascularization with shunting in time to avoid late revascularization syndrome resulting from long-term ischemia (Taras, 1991). Arterial anastomosis is usually performed before the veins are repaired in an amputation proximal to the wrist. Conducted in this order, lactic acid and toxic breakdown products of anaerobic metabolism will not be transported systemically as they would if the veins had been repaired previously (Goldner and Nunley, 1992). Before stabilization, bone ends may need preparation for proper fixation. In a guillotine type of amputation, bone shortening appears to be of paramount importance for performing stable internal fixation and to facilitate further microvascular anastomoses and repair of the tendons (Daoutis et al., 1995). In the case of forearm and transhumeral amputation, some authors prefer using a dynamic compression plate for rigid bone fixation (3.5 mm in radius and ulnar amputations and 4.5 mm in humeral amputations) (Goldner and Nunley, 1992). If there is significant bone comminution or loss, an external fixator can be used, particularly in the forearm

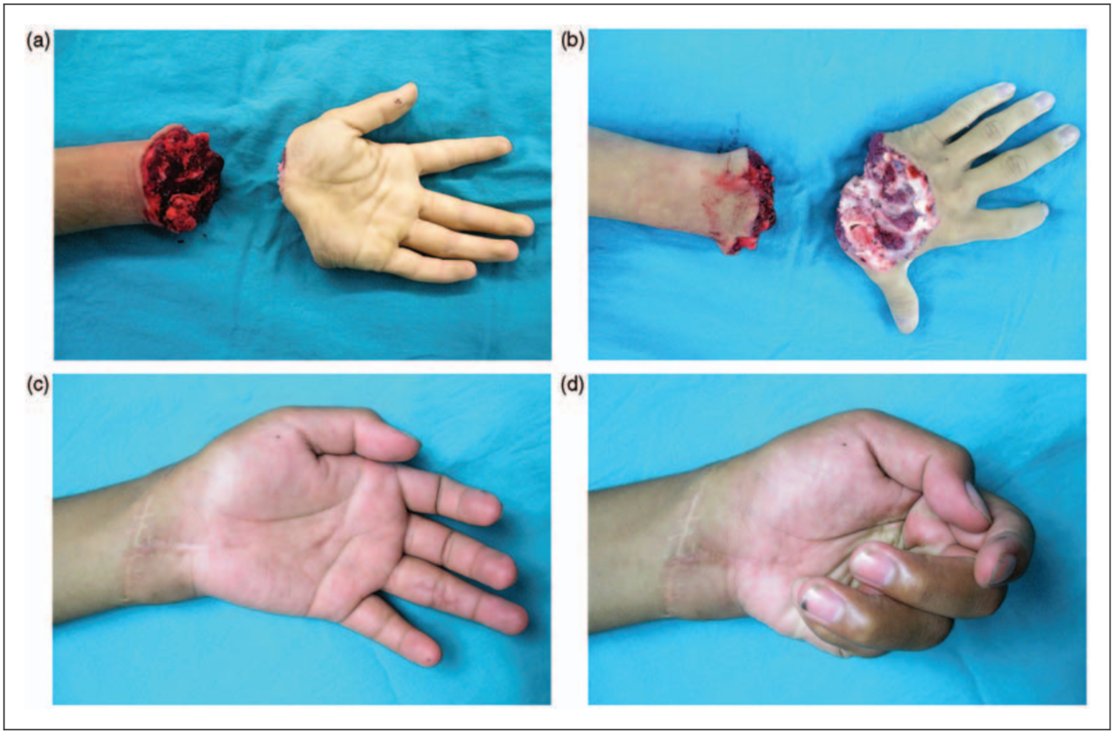

Figure 2. (a) Complete amputation of the left wrist, volar view. (b) Complete amputation of the left wrist, dorsal view. (c) Left hand, digits extended, at 1-year follow-up. (d) Left hand, digits flexed, at 1-year follow-up.

(Weiland et al., 1976). If there is prolonged ischemic time, such as in the delayed presentation of the patient to the emergency room or with poor cold preservation of the amputated portion, we prefer the use of external fixator because its application is quick and could save much time.

Because limb engorgement is an impending problem, as many venous anastomoses as possible should be performed. In the case of major amputations, vein grafts are usually necessary to replace long segments of damaged vessels. Reverse saphenous grafts should be used judiciously so as not to compromise adequate debridement of vessel ends. The most common donor site of vein graft is the dorsum of the foot, but the greater and lesser saphenous systems provide excellent sources for longer grafts. Next, the tendons and nerves are sutured. Remember that lacerated nerves at this level consist of both motor and sensory fascicles and that proper alignment is crucial to obtaining functional nerve regeneration. At this amputation level, it is mandatory to perform a fasciotomy on both sides to avoid compartment syndrome. This is followed by dressing placement and splint immobilization (Idler and Steichen et al., 1992). In cases of major limb replantation, second-look operations sometimes are necessary, days later, to assess the viability of muscle and other tissues.

Postoperative management

After the operation, the amputated limb should be placed in a bulky dressing and kept elevated. The patient should be kept warm in the recovery room and the ward for the first two days to prevent hypothermia and vasospasm (Wijayaratna et al., 2008). Postoperative evaluations should

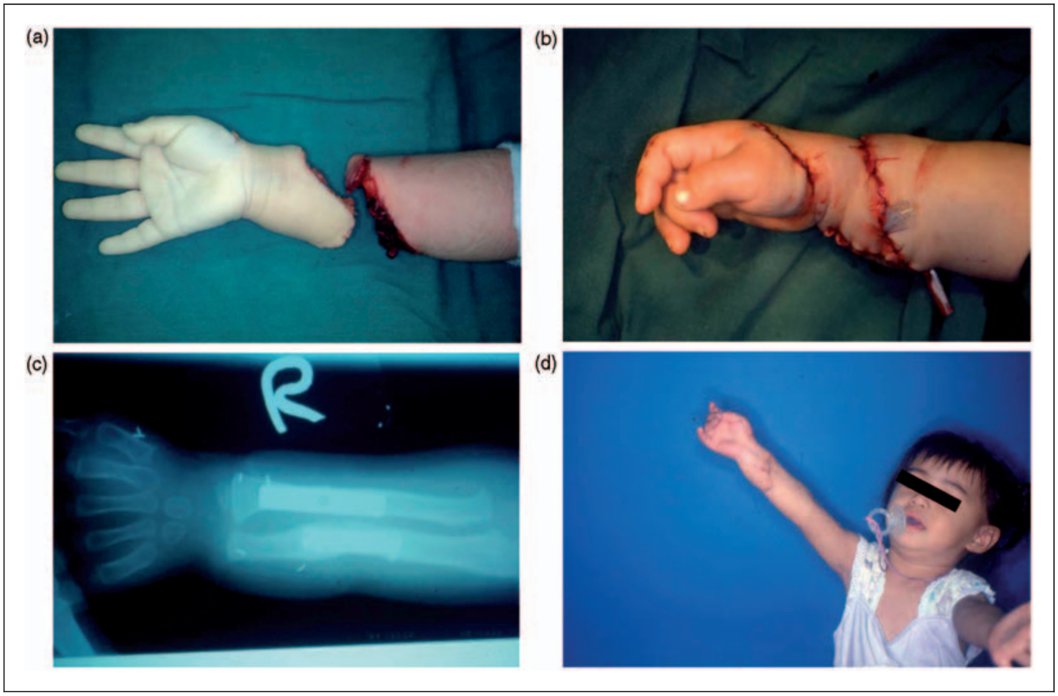

Figure 3. (a) Complete amputation of the right forearm, volar view. (b) Replantation of the right forearm amputation, immediately after operation. (c) Two dynamic compression plates were used for rigid radius and ulnar fixation. (d) The amputated part was totally survived at the 6-month follow-up.

include close monitoring of patient vital signs and circulation in the replanted part. Circulation is evaluated by means of cutaneous temperature, color, capillary refill, and Doppler flowmetry (Hovius et al., 1993). In theory, a decrease in arterial inflow may result in a rapid loss of temperature in the digit, but the decision to re-open still relies to some extent on the experience of the surgeon, to some extent. Reagan et al. (1994) noted that clinical observation, in conjunction with temperature monitoring, provided a 100% sensitivity and 99% specificity in the identification of vascular compromise in replanted digits. In studies by Hovius et al. (1995), however, temperature monitoring alone provided only a 61% specificity in identifying problems in replantations.

Postoperative anti-coagulant medications include various combinations of aspirin, low-molecular-weight dextran, and heparin. Aspirin is given at a dose of 325 mg daily for its antiplatelet effect, and is generally given for a total of 3 weeks postoperatively (Pederson, 2001). With respect to the anticipated effects of anti-coagulant medications, the potential complication of using low molecular weight dextran is fluid overload, particular in both the extremely young and old patients. In addition, acute renal failure after administration of dextran following microsurgery has been reported (Brooks et al., 2001; Tsang et al., 2000) as have cases of anaphylaxis to dextran (Kitziger et al 1990). Morrison recommended that a single bolus of 5000 units of intravenous heparin before releasing the clamps is valuable in facilitating perfusion (Morrison and McCombe, 2007). In the study of Kutz et al. (1983), the use of systemic heparinization is certainly indicated if vascular thrombosis occurs in the operating room or the vessels appear severely damaged. Our preference is that dextran is used only when there is marked blood loss after amputation and, instead of intravenous

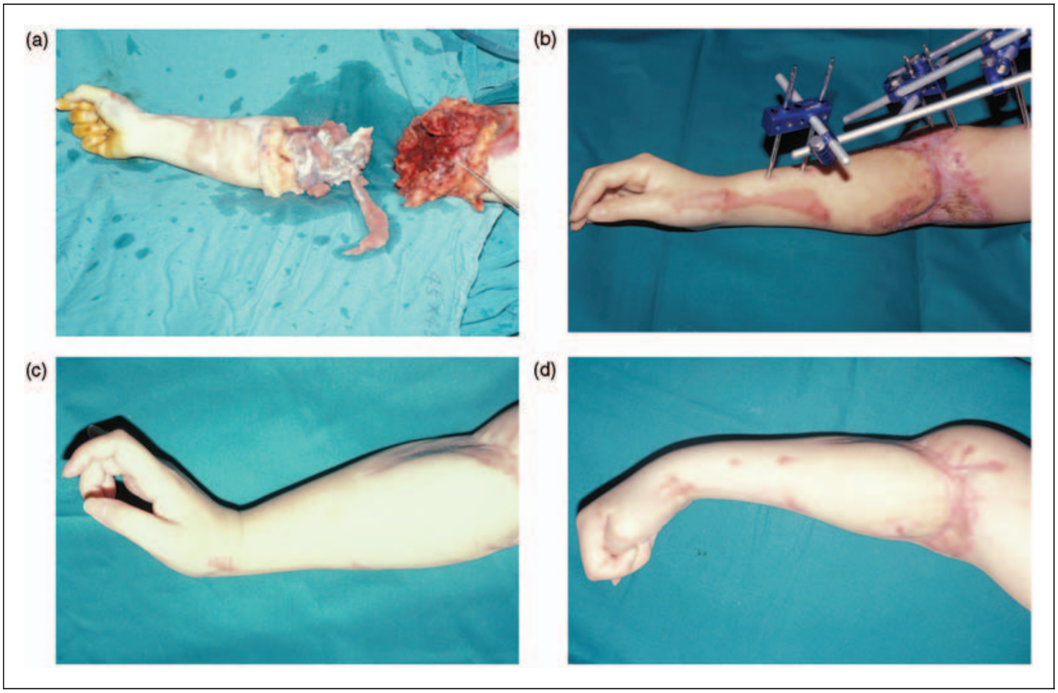

Figure 4. (a) Complete avulsion amputation of the right elbow. (b) Replanted right elbow with external fixation at 3 months after the operation. (c) Right wrist full extension at 1-year follow-up. (d) Right wrist full flexion at 1-year follow-up.

heparin administration, we prefer to use daily subcutaneous injections of low-molecular-weight heparins (e.g. certoparin, dalteparin, enoxaparin, nadroparin, reviparin, and tinzaparin) that do not require monitoring or dose finding. This approach has largely replaced the use of unfractionated heparin for the initial management of venous thromboembolism (Hull and Pineo, 2004).

The most common complication of major limb replantation is sepsis, secondary to muscle necrosis. Therefore, broad-spectrum antibiotics such as cephalosporin and aminoglycosides are administered intravenously for 1 week, followed by oral administration, which varies according to the presence of infection (Beris et al., 1994). Hyperbaric oxygen (HBO) could be an adjunctive therapy in replantation surgery after prolonged warm ischemia or if there is significant associated crushed skin and soft tissue damage. In the study of Salgado et al. (2010), if adjunctive HBO therapy can be employed in the postoperative period, replantation of an amputated rat hind limb may be successfully conducted even after prolonged ischemia in a warm environment. Clinically, Chen et al. reported good results in salvaging tissues that controlled studies showed would certainly have died (Zhong et al., 1981). Chew and Tsai (2001) advocated the routine use of HBO therapy for all major limb replantations to decrease swelling, prevent potential compartment syndrome, and help control deep infections.

Adequate postoperative physical therapy is one of the most important factors for achieving a functional hand. Postoperative rehabilitation includes edema management and early motion to maintain joint pliability and prevent tendon adhesions. The rehabilitation protocol from Papanastasiou's study provides a basic guideline for early protective motion from weeks 1 through

6, later intermediate treatment from weeks 6 through 12, and a strengthening stage from week 12 to 4 months (Papanastasiou, 2002).

Outcome

The most important factors that influence the overall success rate for replantation surgery are the types of injury. It is obvious that crush-avulsion injuries have worse survival rates in replantation than guillotine type amputations. Patients with guillotine amputations had a higher survival rate, fewer complications, and better functional results when these injuries were compared to crushing or avulsion injuries (Russell et al., 1984). Saies et al. (1994) also reported on the results of replantation and revascularization in children. The rate of replant survival was 72% when the amputation had resulted from a laceration injury and 53% when the amputation had resulted from a crush or an avulsion injury.

However, success of replantation must not be associated with tissue survival but measured in terms of what the effort has done for the patient (i.e. functional recovery). The factors that tend to favor functional outcomes in replantation surgery include younger patient ages, a sharp and single level of injury, and a more distal site of amputation. On the other hand, factors that tend to give negative functional results include extremes of age, crush or avulsion injuries, multilevel injuries, and more proximal levels of replantation; particularly those that pass through large masses of muscle. Russell et al. (1984) presented the late functional results of upper limb revascularization or replantation in 34 patients. High-level injuries were associated with more extensive soft tissue damage, a lower survival rate, and poor functional results.

The level of injury has a substantial effect on the functional outcome of replantation (Weiland and Raskin, 1990). Generally, the more proximal the amputation of the extremity part, the worse the functional result of replantation. The reasons for proximal amputations having poorer recovery of function are as follows: first, there is more muscle mass in the proximal limb. The amount of muscle mass makes amputation at this level less susceptible to ischemic time and reperfusion injury. Second, more proximal amputations require greater time for the detached nerves to regenerate. The longer the distance that a nerve is required to regenerate before reinnervating the muscle, the worse the recovery secondary to motor endplate loss and muscle fibrosis. In addition, the complexity of mixed motor and sensory fascicles at the proximal level results in a greater possibility for the mismatch of regenerative motor fascicles to the sensory pathway. In 1986, Wood and Cooney presented the functional results for 7 patients with above elbow amputations. Only two patients had obtained useful function in the hand and digits (Wood and Cooney, 1986). Chew and Tsai (2001) reviewed 34 cases of complete above wrist amputations between 1977 and 1997. Of these, 8 limbs required secondary amputation 1 to 21 months after successful replantation. In the successful replant group, 57% achieved good or excellent functional outcome results. In this study, they also concluded that injury level and ischemic time were statistically significant in affecting the functional outcome. Paavilainen et al. (2007) reported on transmetacarpal revascularization in 22 patients and replantation in 21 patients. The long-term results revealed that most patients had good subjective and satisfactory functional end results and could resume their previous occupations or be employed after physical re-education. Similarly, Blomgren et al. (1988) reported on 17 patients with upper limb amputations receiving replantations. Hand function was evaluated as restricted in patients with amputations at the lower arm to wrist level, fair at the midhand level, good at the metacarpal-phalangeal level (or distal on the 2^{nd} to 5^{th} fingers), and best in replanted thumbs. Sensibility was poor in a majority of the patients.

The same situation is described for digital amputations. The level of amputation of a digit can also affect its functional capacity.

Table 2. Chen's criteria for evaluation of functional result after upper extremity replantation.

Grade	Function
I	Able to resume original work, range of motion exceeds 60% of normal, complete or nearly complete recovery of sensibility, muscle power of grade 4
II	Able to resume some suitable work, range of motion exceeds 40% of normal, nearly complete sensibility, muscle power of grade 3 and 4
III	Able to carry on daily life, range of motion exceeds 30% of normal, partial recovery of sensibility, muscle power of grade 3
IV	Almost no usable function of survived limb

Overall, better functional results are seen in replants distal to the FDS insertion. A systematic review of distal digital replantation from Sebastin and Chung (2011) mentioned that the mean survival rate of replantation was 86%. With respect to the functional outcomes, the mean two-point discrimination was 7 mm, and 98% of the patients returned to work. This review shatters the common perception that distal replantation is associated with little function. Saies et al. (1994) also noted that total active motion was significantly better when the level of amputation was distal to the insertion of the FDS tendon. Some authors have indicated that replantation was not done, in the case of fingertip amputations, if no suitable vein was found for anastomosis (Venkatramani et al., 2011). In such scenarios, our proposed subdermal pocket procedure can offer an alternative salvage procedure with a high success rate (Lin et al., 2004). On the other hand, the replantation of digits in flexor zone II is controversial because of limited success in achieving functional motion. Adhesions between the FDS and FDP, as well as interphalangeal joint contractures, will compromise total active motion of replants. The final functional outcome is decided not only by the injury itself, but also the patient's age, underlying disease, overall expectations, compliance with rehabilitation, and psychosocial disposition.

Most of the functional outcomes of replantation could be evaluated following the principles introduced by Chen et al. (1978) (Table 2). Daoutis et al. (1995) reported on 28 incomplete nonviable amputations with total replant survival and 19 complete major amputations with replant survival in 14 of the 19 cases (74% success rate). In this study, the functional results showed 15 patients achieving grade I, 11 grade II, 16 grade III, and 5 grade IV. Bora et al. (1993) presented their experiences in replantation in 1993. There were 83 cases (136 replants) with the overall success rate being 82%. The functional results were evaluated as very good in 14 patients, good in 35, moderate in 24, and poor results in 5. Ipsen et al. (1990) presented 23 upper limb replantations or revascularizations with a survival rate of 83%. The functional outcomes were also evaluated following the principles outlined by Chen et al. with 63% having good or excellent results.

Conclusion

The advent of microsurgery has led to replantation of almost every amputated part of the upper limb. Replantation of digits and the hand can restore not only circulation but also function and cosmetic appearance. However, major amputations remain a challenge to the reconstructive surgeon. Although the success rate of replantation exceeds 80%, the functional outcome following major limb replantation is often disappointing. Proper patient selection, pre-theater preservation, good operative skill, postoperative care, and cooperation between the patient, surgeon, and rehabilitation therapist all help to achieve a better final functional outcome.

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Conflicts of interest statement

There is no conflict of interest.

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