**Original Article**

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# Evaluation of functional recovery after upper limb replantation

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## ABSTRACT

**Background**: Although it is not possible always, reconstruction of defects with tissue such as defect in the original tissue usually results in best functions and esthetic outcomes. Therefore, replantation of an amputated part is superior to any other method of reconstruction mainly when the condition of the amputated part is good. The goal of replantation after amputation is function. Returning of circulation to an amputated part does not, by itself, mean success. Therefore, replantation that will not lead to a useful activity should be avoided. This is usually the case with severely crushed and extensively avulsed limbs.

**Objectives**: evaluation of functions' outcome after replantation.

**Patients and Methods**: This study deals with 18 patients (14 males, 4 females) with different injuries. Severely crushed and extensively avulsed limbs have been excluded from repair. The level of injury involved an arm in two patients, an elbow in one, a forearm in two, a palm in two, a thumb in two, and fingers in nine. The patients' age ranged between 2 and 55 years, during the period between January 2012 and February 2016.

**Results**: In all the cases, replantation of the amputated part was successful; however, there were variations in functional recovery among the cases: in three cases, the functional recovery was very good, in five, it was good, in eight, it was fair, and in two, it was poor.

**Conclusions**: Replantation should be tried for most amputation cases, as it has a superior aesthetic and functional result and serves a major psychological benefit for the patients. High success in a rat can be achieved when one chooses to replant an amputated part in good condition, all the structures are repaired at the time of the primary operation, and there exist excellent post-surgery physiotherapy and good patient compliance.

**Keywords**: Replantation; amputation; vascular repair, limb trauma, revascularization, microsurgery.

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## INTRODUCTION

Only a center can provide the necessary team, which includes a qualified micro-surgical team, experienced operating-room personnel, dedicated operating-room time, appropriate operative microscopes and instrumentation, adept perioperative nursing care, and an experienced hand therapy unit. Parts without muscle tend to survive with warm ischemia time of about 10 to 12 hours, although successful replantation has been reported after 24 hours of warm ischemia. Much longer periods of cold ischemia are consistent with survival. More proximal injuries with more muscle mass in the amputated part can tolerate 6 to 8 hours of cold ischemia. Indications for replantation must now reflect functional considerations. Major indications for replantation include the amputations of a thumb, multiple digits, and in children. Major contraindications include life-threatening injuries and severe underlying diseases that preclude the safe undertaking of such lengthy operations. [(1)]

The most important factor to determine the survival rate and the functional outcome is the type of injury. [(2)] Guillotine, avulsion, crush, or a combination of any of these injuries can occur. Guillotine injury is sharp injuries with no effect on the tissues away from the site of amputation. Blunt crushing injuries damage tissues beyond the site of amputation, but near the site of amputation. Distraction or torsion injuries cause tissue damage at variable distances, away from the site of amputation. Nerves and vessels stretching during avulsion or torsion injury usually cause longitudinal injury along with these structures, making a very poor prognosis. [(3)]

The site of amputation is the second most important factor in determining the survival rate and the functional outcome. The literature suggests that the more proximal the amputation, the greater the incidence of complications and the worse the functional results. In the case of more proximal amputation, early return of circulation will prevent muscles ischemia, and concomitant nerve repair will decrease muscles atrophy. [(4)]

When a nerve does not repair, this leads to an insensate part with poor cold intolerance, subject to substantial neuropathic pain and poor function. Therefore, a basic understanding of the technical aspects of nerve repair including the type of repair required (e.g., epineuria vs. fascicular), the appropriate selection of a conduit when necessary, and a thorough knowledge of the methodologies for assessing functional recovery are essential. [(5)]

### Types of Nerve Repair

1.***Direct nerve repair***

*Epineural Repair*

Used for clean-cut injury and end-to-end epineural repair (Fig. 1) and has a goal of cooptations of nerves without tension.

*Fascicular Repair*

Using fascicular or grouped fascicular repair (Fig. 2). In this repair, the perineurium sutured, or, in groups of fascicles, the internal epineurium is situated for cooptation.

***2.Nerve Conduits***

Bone shortening helps nerve repair, but there are several situations where tensionless repair is not possible, even with bone shortening, such as the absence of part of the nerve, crushed nerve, and avulsed nerve. Further, when the primary repair cannot be achieved, significant nerve contraction occurs making direct end-to-end tensionless repair impossible. All these conditions require nerve conduits for nerve repair (Fig. 3). [6]

### *3. Nerve Autografts*

When it is impossible to repair a nerve directly, a nerve graft or even a nerve transfer needs to be considered. The best way to deal with a nerve gap is through nerve autograft. [7]

## Level of injury

### *Arm replantation*

In replantation of the arm, a long time is required for nerve regeneration, and functional recovery tends to be poor due to joint stiffness, muscular degeneration, and poor nerve regeneration, especially in a crushed arm or in an elderly patient. Therefore, the decision for replantation should be taken more cautiously compared to distal amputations. The requirements for the selection of a patient for replantation of the arm are as follows: a healthy person under the age of 60, no other serious or life-threatening injuries, good

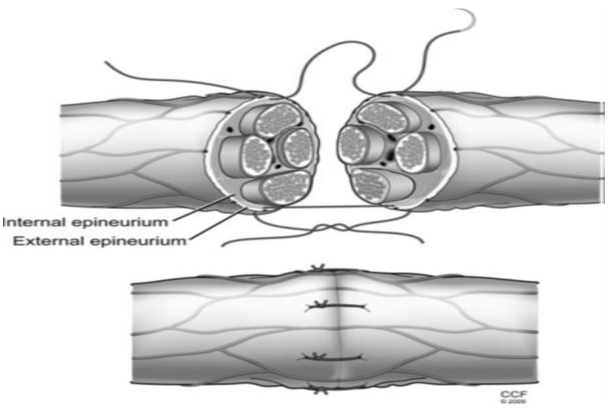


**Figure 1:** In epineural repair, only the epineural layer is sutured to achieve the approximate nerve ends.

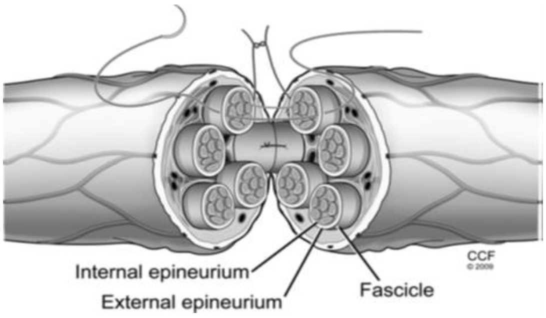


**Figure 2:** In fascicular repair or grouped fascicular repair, the perineurium is sutured to the approximate nerve ends.

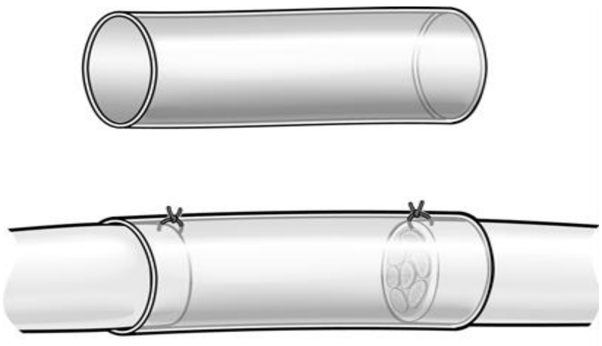

**Figure 3:** Bridging two nerve segments with a nerve conduit.

condition of the amputated part, and a person who can follow a long period of physical therapy and multiple reconstructive procedures. [8]

### *Forearm replantation*

Regarding the functional outcome, a clear-cut amputation in the distal forearm can generally achieve good results. On the other hand, replantation of a crushed amputation in the proximal forearm gives less favorable results. Generally, any kind of forearm amputation is a candidate for replantation; however, patients with severely crushed muscles, diabetes, concomitant organ trauma, or peripheral vascular disease should be excluded. [9]

### *Hand Replantation and Digits*

According to Tamai's definitions of the zones of the hand and digits, the hand is the zone from the distal palmar crease to the wrist joint. Replantation of the hand is usually associated with a good outcome when the condition of the amputated hand is favorable. Management should be individualized according to the patient's occupation, and overall health. skeletal stability, power, degree of joint mobility, and sensibility can help determine functional success. [10] Multiple digits should be replanted in the order of the importance of the involved digits. The ring and the long finger are usually cited as the fingers of greatest importance as they perform both grasp and pinch. [11]

The thumb should be replanted at any level. Although the thumb functions as a post for pinch as well as grasp, the length is important. Even if the nerves or the tendons are avulsed from the distal part, subsequent reconstructive procedures are available for functioning. Relative contraindications to digit replantation include single digits, distal tip amputations, excessive warm ischemia time, and an age greater than 75 years. [12]

### Method of evaluation

There are different methods to evaluate the functional outcome of the replanted limb. Chen's criteria is a simple method that can be used for this purpose (Table 1). It measures the level of sensory recovery, the range of joint motion, and muscle power.

**Table 1:** Chen's criteria for the evaluation of function after extremity replantation.

| Grade / Function | |
|---|---|
| I | Ability to resume original work with a critical contribution from the reattached parts; a range of motion (ROM) exceeds 60% of normal, including the joint immediately proximal to the reattached part; recovery of sensibility to a high grade without excessive intolerance of cold; muscular power of 4 to 5 on a scale of 1 to 5. |
| II | Ability to resume some gainful work but not original employment; ROM exceeds 40% of normal; recovery near-normal sensibility in the median and ulnar distribution without severe intolerance of cold; muscle power of grade 3 to 4. |
| III | Independence in activities of daily living; ROM of joints exceeds 30% of normal; poor but useful recovery of sensibility (for example, only median or ulnar recovery is good or quality is only protective in both median and ulnar areas); muscle power of grade 3. |
| IV | Tissue survival with no recovery of useful function. |

## PATIENTS AND METHODS

Eighteen patients with amputations underwent replantation procedures at the Al-Wasity Teaching Hospital in Baghdad from 2012 to 2016. Fourteen patients were male and four were female. Their ages ranged from 2 to 55 years. The total ischemic time ranged from 4 to 12 hours before replantation, and the average ischemia time was 8.6 hours (Table 2). The operation time ranged from 5 to 10 hours with an average time of 7 hours. The level of injury involved an arm in two patients, an elbow in one, a forearm in two, a hand in two, a thumb in two, and fingers in nine. The mechanism of injury in eight patients was clear cut, in seven was crush with or without torsion or avulsion, and in three was torsion/avulsion. We regarded the crush, torsion, or avulsion injuries as a mild one when bone shortening precludes the nerves or the vessel grafts and the neurovascular bundles are sutured without any tension. The injury with moderate severity required, in addition to bone shortening, grafts to achieve the tensionless repair. The severely injured limb suspected to show no or poor functional recovery in the future was excluded from the repair.

The exploration and the structure identification of the amputated part should be carried out in the operating room as early as possible after the patient's arrival to the hospital to shorten the operation time.

Local anesthesia was used in two patients and general anesthesia in sixteen patients. A tourniquet was used during the dissection in the proximal stump, which is performed under 2.5 magnifications with a binocular loupe or under the microscope in the case of amputation distal to the wrist. After the routine of brushing and washing with copious amounts of physiological saline solution containing antibiotics, radical debridement was performed with a knife and scissors to remove all the contaminated and crushed tissues. An additional skin incision was made to obtain a wider operative field.

One or two arteries, two veins or more, and all the nerves and tendons were identified. Once these structures were located, stay and marking sutures were applied. Physiological saline containing heparin (1000 IU) was injected from the arteries to wash out the toxic metabolites from the amputated part and any residual blood to prevent thrombus formation, which should continue until the clear fluid has come out from the vein.

**Bone Fixation**

Shortening of the bone is very important to facilitate the repair of arteries, veins, nerves, and tendons, and to facilitate skin closure. More bone shortening is required when there are more soft tissue gaps. Stable fixation of the bone is necessary, and the method must be rapid.

The Kirschner-wire fixation will provide adequate stability from the level of wrist distally. For more proximal level replantation, the unilateral external fixator is used. Plate and screw fixation are preferable, but too much stripping of the muscle may cause muscle ischemia.

**Vascular Anastomosis**

In distal amputation, vein anastomoses were carried out prior to performing arterial anastomoses to avoid excessive blood loss. However, when the ischemic time of the amputated part exceeded 4h, the artery was anastomosed first to avoid prolonged ischemia. In proximal forearm amputation, where the amputated part includes much muscle tissue, arterial repair was performed before venous repair because the rapid return of blood with toxic substances, including lactic and pyruvic acid, can be detrimental to the patient. In such a situation, the returning blood from the replant bleeds freely for a while until the color of the blood becomes pink. Before the anastomosis of the vessels, intravenous perfusion with heparin was used to prevent thrombosis. A superficial network of the vein was used for anastomosis because these veins are of good sizes mainly when the amputation is at the wrist or, more distally, when the comitantes are small (Fig. 6). Since muscle ischemia leads to increased permeability and compartmental swelling occurs following revascularization, fasciotomies are performed in major limb replantation. Before the wound is closed, the drainage was used to prevent hematoma, which compresses the sutured vessels. The drainage tube or sheet is placed far away from the site of vessel anastomoses to ensure there is no mechanical interference at the anastomoses' site.

**Repair of the Muscles, Tendons, and Nerves**

The deeper structure is repaired first. Nerve suture is performed with epineural sutures using 8-0 nylon. The tendons and the muscle belly are repaired with 3-0 nylon modified Kessler and 3-0 nylon figure of eight, respectively.

**Skin Closure**

Finally, the skin is closed, with or without skin grafting. In particular, any exposed vessels or nerves need to be covered by local skin as much as possible, and additional split-thickness skin should be grafted as needed.

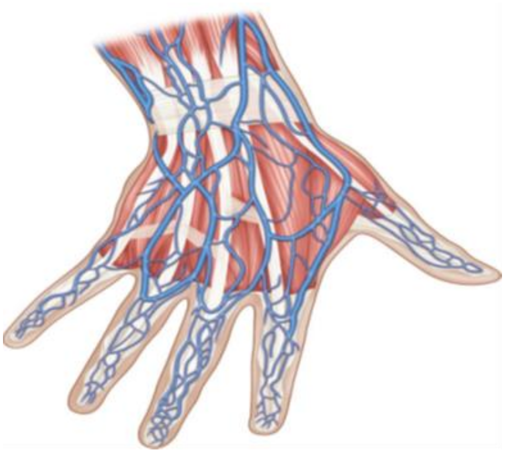

**Figure 4:** Superficial dorsal veins used for vein repair mainly when the level of amputations is distal to the wrist as these vessels have a larger diameter than venae comitantes in this level.

**Postoperative Management**

A bulky dressing must be used and carefully applied, and a bandage should be applied loosely to avoid any compression of the vessels. Postoperatively, the limb is elevated continuously, and the fingertips are inspected at regular intervals. Vital signs and the skin temperature of the digits are monitored. To prevent vascular thrombosis, the intravenous perfusion of heparin is routinely used for one week after the operation. Physiotherapy starts ten to fourteen days post-surgery and continues for more than two years in major replantation.

**Table 2**: Eighteen patients were chosen in this study with different mechanisms of trauma and different levels of injury.

| cases | Age/Sex | Cause of amputation | Level of amputation | Soft tissue condition | Ischemia time in hours (Cold or hot) |
|---|---|---|---|---|---|
| 1 | 44/M | Straw compression machine | Distal forearm | Mild crush | 10 cold |
| 2 | 20/M | Road traffic accident | Proximal arm | Mild crush\avulsion | 6 cold |
| 3 | 32/M | Sword | Proximal hand | Clean cut | 4 hot |
| 4 | 22/M | Cutter for paper | Mid-palm | Clean cut | 8 cold |
| 5 | 31/F | Washing machine | Proximal phalanx of the index | Mild torsion\avulsion | 4 hot |
| 6 | 4/F | Agriculture machine | Distal-arm | Moderate crush\ avulsion | 6 hot |
| 7 | 27/M | Heavy object | Middle phalanx of the index | Clean cut | 5 cold |
| 8 | 3/M | Woodcutter | PIP of middle finger | Clean cut | 4 cold |
| 9 | 2/M | Road traffic accident | Elbow | Mild crush | 12 cold |
| 10 | 25/M | Road traffic accident | Proximal forearm | Mild crush | 5 cold |
| 11 | 18/M | Cutter for iron | Proximal phalanx of thumb | Clean cut | 5 hot |
| 12 | 4/M | Closure of a door | Proximal phalanx of middle finger | Moderate crush | 8 hot |
| 13 | 55/M | Woodcutting saw | Middle phalanx of four fingers | Clean cut | 7cold |
| 14 | 19/M | Closure of a door | Proximal phalanx of thumb | Mild crush | 9 cold |
| 15 | 16/F | Washing machine | Proximal phalanx of middle finger | Moderate torsion\avulsion | 6 hot |
| 16 | 3/M | Fitness bicycle | Distal phalanx of little | Clean cut | 4 hot |
| 17 | 48/F | Washing machine | Proximal phalanx of the index | Mild torsion\avulsion | 5 cold |
| 18 | 14/M | Heavy object | Middle phalanx of the index | Clean cut | 7 hot |

**A**

**B**

**D**

**C**

**Figure 5:** Amputation at the level of PIP of the right middle finger. **A**, proximal stump. **B**, distal part. **C** and **D**, 14 months post replantation with very good recovery of the function. The patient experienced a new trauma that involved their index finger several months after replantation of the middle finger.

**A**

**B**

**C**

**D**

**E**

**F**

**Figure 6:** Guillotine type amputation by a sword at the proximal hand. **A, B**, clean cut at distal part. **C**, proximal stump. **D, E**, external fixation and minimal proximal and distal dissection to minimize soft tissue damage**. F** and **G,** good flexion of the fingers and good apposition of the thumb against the digits.

**G**

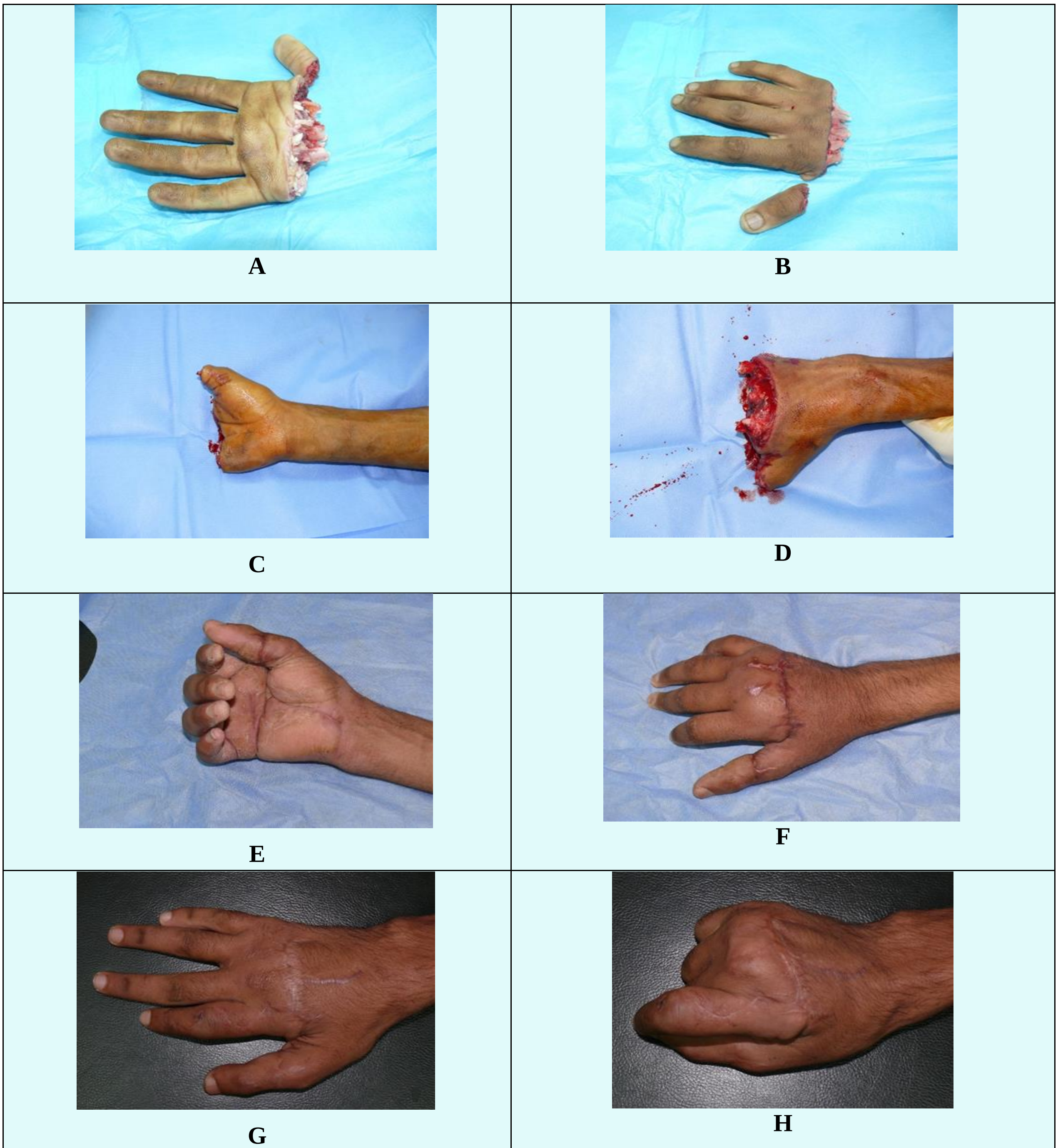


**Figure 7:** Amputation at mid-palm and proximal phalanx of the thumb caused by the cartoon cutting machine. **A** and **B**, volar and dorsal aspect of amputated part. **C** and **D**, volar and dorsal aspect of a stump. **E** and **F**, two months after replantation. H, two years after replantation. The patient was able to perform good flexion at the fingers except for limited movement in the MP joint of the index.

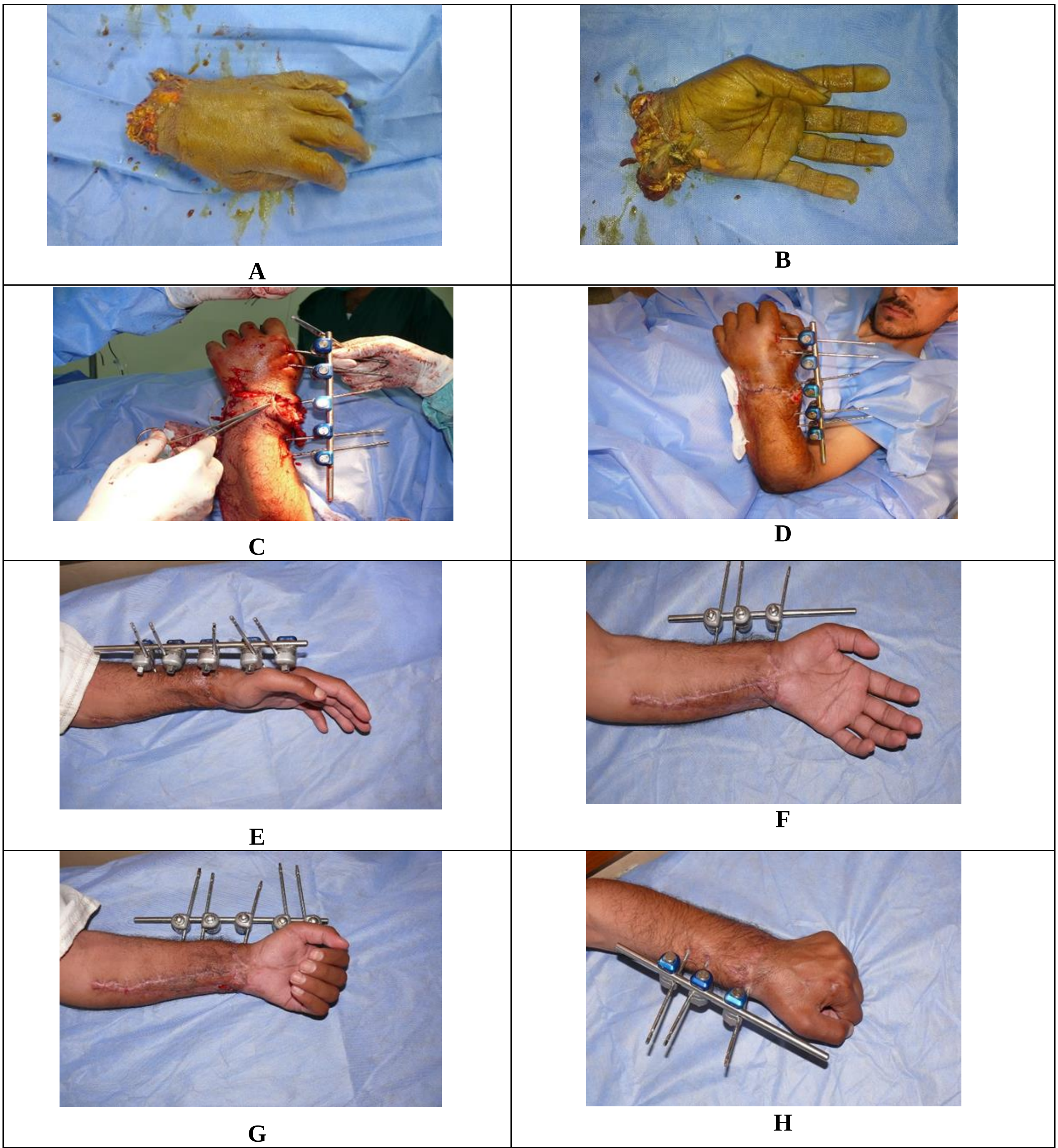


**Figure 8:** Amputation at distal forearm caused by the straw compression machine with a mild crush. **A** and **B**, volar and dorsal aspect of the amputated part after disinfection with povidone-iodine. **C**, intraoperative wound closure. **D**, five days postop. **E**, **F**, **G,** and **H**, three months after replantation with good pronation of the forearm and good flexion of the digits.

## RESULTS

Of the 18 patients analyzed, most (83%) of the cases were male. The right side was affected in 77.7% of the cases. The ischemic time ranged from 4 hours to 12 hours (average 8.6 hours).

All of the replanted parts survived. The follow-up periods of the patients ranged from 1 to 5 years, averaging 32 months. These patients required multiple secondary reconstructive procedures for the nerve, tendon, skin, and bone. The recovery of functions was evaluated by Chen's criteria. According to these criteria, the results were very good in three patients, good in five, fair in eight, and poor in two (Table 3).

**Table 3**: The final evaluation of functional recovery according to Chen's criteria.

| Case no. | age year | sex | Level of amputation | Chen's criteria | Final evaluation |
|---|---|---|---|---|---|
| 1 | 44 | M | Distal forearm | II | Good |
| 2 | 20 | M | Proximal arm | IV | Poor |
| 3 | 32 | M | Proximal hand | II | Good |
| 4 | 22 | M | Mid-palm | II | Good |
| 5 | 31 | F | Proximal phalanx of the index | III | Fair |
| 6 | 4 | F | Distal-arm | II | Good |
| 7 | 27 | M | Middle phalanx of the index | III | Fair |
| 8 | 3 | M | PIP joint of middle finger | I | Very Good |
| 9 | 2 | M | Elbow | III | Fair |
| 10 | 25 | M | Proximal forearm | III | Fair |
| 11 | 18 | M | Proximal phalanx of thumb | I | Very good |
| 12 | 4 | M | Proximal phalanx of middle finger | III | Fair |
| 13 | 55 | M | Middle phalanx of four fingers | III | Fair |
| 14 | 19 | M | Proximal phalanx of thumb | II | Good |
| 15 | 16 | F | Proximal phalanx of middle finger | III | Fair |
| 16 | 3 | M | Distal phalanx of little | I | Very good |
| 17 | 48 | F | Proximal phalanx of the index | IV | Poor |
| 18 | 14 | M | Middle phalanx of the index | III | Fair |

## DISCUSSION

As any injury anywhere in the body, the healing process results in the laydown of the fibrous tissue in all the layers of the wound. After replantation, all the structures will adhere together making any subsequent procedure more difficult.

The goal in all the operations for all the patients was to restore as much of the function as possible, which indicates that all the structures and mainly nerves should be repaired primarily as the time factor in muscles' re-enervation is crucial and secondary procedure has less favorable conditions as a result of adhesion and retraction of the nerves and other structures.

Although avulsed nerves present damage exceeding the skin level of the amputation, they are best reconstructed at the same time of replantation. [13] A simple surgical technique, which is often used in most of the 18 patients, is bone shortening. Bone shortening allows the neurovascular bundle to be approximated, which helps in the primary repair of vessels and nerves. [14]

In all the 18 cases, all the structures were repaired at the time of the first surgery. This helps in uninterrupted physiotherapy, decreases the fibrosis and adhesion from secondary procedures, and shortens the time interval between nerve repair and muscles reinnervation. With each additional procedure, the swelling and post-surgery pain will decrease the level of patient compliance for physiotherapy, which will increase the chance of joint stiffness and tendon adhesion.

All the above indicate that the key to achieving the maximum functional recover is to typically repair all the elements together in one surgery and the continuous uninterrupted physiotherapy.

In this study, the result generally indicates that the regaining of useful control of the amputated part improves with more distal amputations. Functional recovery is best when the amputation involves the wrist or the wrist more distally. The same conclusion was found in A. Neil Salyapongse et al.'s study, which stated wrist replantation can achieve high functional results and excellent patient satisfaction, and the replantation of digits tends to be one of the most difficult but rewarding procedures in hand replantation surgery. [15] With more distal amputation, there are smaller quantities of soft parts that are affected by longer acceptable ischemic time. [16]

Functional outcomes in children after replantation are better than those performed in adults. [17] In three of the eighteen patients included in this study, the functional recovery was very good according to Chen's criteria; two of them were children. The other children also showed better scores than the adults with a comparable level of injury, which indicates that replantation in children results in better restoration of function.

Most of the finger injures in this study occurred in zone II, and the functional result was usually fair except in one case with very good and one case with poor outcome, which may reflect the type of trauma, the patient compliance to physiotherapy, and adhesions. Adhesions of flexor tendons is a common cause of functional impairment in this zone. [18] Injuries to zone II have less functional results than injuries involving zones proximal and distal to zone II. [19]

All the patients who followed up for a long period are grateful for their limb retrieval and are either pain-free or have a mild but tolerable pain during the full range of movement. Even the two patients with poor function have benefitted from the psychological aspect of the replantation. As validly stated by Sterling Bunnell, a “bad hand” is functionally better than a “good amputation.”[20]

## CONCLUSION

Replantation should be tried for a vast majority of amputation cases, as it has a superior aesthetic and functional result and major psychological benefits for patients, mainly children. Replantation of most levels of amputation can be achieved with a good or fair functional success when the surgeon chooses to replant an amputated part with a good soft tissue condition, when good preservation of the amputated part is there, all the structures have been repaired at the time of replantation, and there is a suitable time interval between the injury and the surgery. After replantation, continuous systematic physiotherapy and a good patient compliance is vital in regaining as much of the limb function as possible.

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