Forearm Amputations and Crush Injuries, Different Scenarios and Treatments: Educational Corner

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Received: 02 May 2021; **Revised:** 08 July 2021; **Accepted:** 10 August 2021

Keywords: Amputation; Hand; Reimplantation; Trauma

Citation: Khajeh R, Moharrami A, Farzan M, Molaei H, Moazen-Jamshidi MM, Zarei M. **Forearm Amputations and Crush Injuries, Different Scenarios and Treatments: Educational Corner.** *Orthop Spine Trauma* 2021; 7(3): 105-13.

Case Presentation

A 26-year-old man was referred to the emergency medical services of our tertiary center in Tehran, Iran, with a crush injury of his right forearm (Figure 1). Past medical and drug histories of him were negative. The patient was an opium-addicted and cigarette-smoker and had a history of open reduction and plating of right ulna about ten years ago.

Figure 1. The photo of transradial amputated upper limb

What Is Your Plan in the Emergency Room (1, 2)?

- Fluid resuscitation with normal saline or Ringer serums was done. A blood sample was sent for hemoglobin (Hb), blood urea nitrogen (BUN), creatinine (Cr), sodium (Na), potassium (K), and the reserve of packed cells.
- Intravenous (IV) antibiotics should cover both gram-positive and gram-negative organisms. In circumstances of gross contaminations such as farmyard injury or fecal contact, anaerobic bacteria also must be covered. Tetanus prophylaxis would be considered for a patient who has an unknown or negative history of vaccination.
- Irrigation and debridement of obviously contaminated tissues along with foreign bodies were made in the emergency room. Sterile dressing was applied for coverage and better control of bleeding. X-rays of remaining amputated parts and above joints were taken to identify the status of associated injuries and determine whether skeletal fractures are reconstructable or not. In torsional injuries, above bones or joints may be involved, so radiographs of proximal portions including the forearm, arm, elbow, and shoulder are recommended. Doppler sonography of vessels of the entire remaining upper extremity is performed to exclude any thrombosis and show the status of vessels.
- Anteroposterior (AP) and lateral radiographs of the forearm and elbow were done (Figure 2).

Figure 2. The primary radiography of amputated forearm

What Is Your Next Plan?

- Salvage vs. amputation?
- Primary vs. secondary?
- Level of amputation?

Primary transradial amputation was done for the patient, as seen in figure 3 (AP and lateral X-ray).

Figure 3. The remained radius and ulna bones measured with preoperative radiography

Transradial Amputation

- The incidence of major upper extremity amputation is 25% of all amputations (1). 41000 transradial amputations were performed in the United States (US) in 2005 (2). Major upper extremity amputation affects the quality of life (QOL), including occupation, hobbies, daily activities, and social and aesthetic problems. The main etiology of upper extremity amputation is trauma (90% due to trauma in Scandinavia) (3), which is indicated in cases of severe neurovascular damage to extremity and severe injuries to the skeleton (4). Other indications of upper extremity amputation consist of malignant tumors (large or recurrent sarcoma) (5), about 25% of electrocution injuries (6), almost 4% of deep thermal burns (usually due to dead tissues, but occasionally for wound sepsis) (7), and infections, especially invasive fungal infection such as mucormycosis that requires amputation in 92% (8).
- If the functional outcome of the salvaged limb would be significantly worse than that of a prosthetic limb, acute amputation is a reasonable option. In some patients, several salvage surgeries in substantially injured extremity would be unsuccessful and even risky to the patient's health.
- Transradial amputation is frequent in the upper extremity, and the following technical points must be considered. Skin incisions in fish-mouth incisions consist of equal-length flaps along with the volar and dorsal aspects of the forearm. Osteotomies in radius and ulna must be done at least 1 to 2 cm proximal to the skin incision. Antebrachial fascia is incised at the level of the skin incision. Radial and ulnar arteries need ligation, but cauterization of interosseous vessels is sufficient. All of the nerves should be dissected proximally and then divided to avoid postoperative neuromas. Flexor and extensor muscles are divided 1 cm distal to the osteotomy level. Incision of the periosteum along with proximal elevation of a small cuff of it is performed to prevent the next bony overgrowth and subsequent wound problems. To do myodesis, first, deeper muscle bellies are fixed firmly to the underlying bone. Superficial muscles are sutured in agonist/antagonist pairing over the end of osteotomies (to provide durable bony coverage, prevent postoperative bursitis, and re-create physiologic tension to superficial muscles to provide maximum contractions) (Figure 4). Drainage catheter and bulky compressive dressing are applied (9).

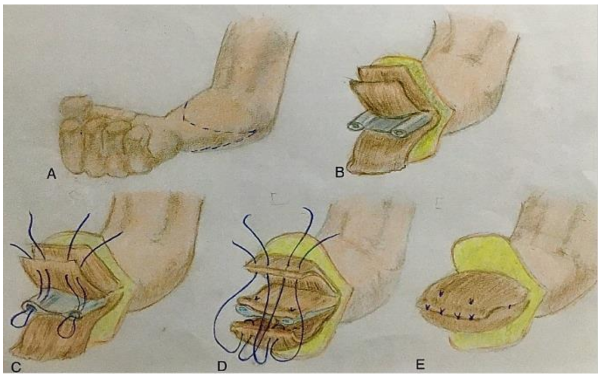

Figure 4. Surgical technique of transradial amputation. A) Fish-mouth incision is 1-2 cm lower to the osteotomy site, 8-10 cm above the ulnar styloid; B) Elevation of soft tissues and osteotomies of radius and ulna by an oscillating saw; C) Myodesis (firm fixation of deep muscles to bones); D and E) Suture of agonist to antagonist superficial muscles over the top to reproduce physiologic tension

- Wrist disarticulation preserves limb length and distal radioulnar joint (DRUJ), thus resulting in better prosthetic control and forearm supination and pronation, respectively. However, the prosthesis, especially myoelectric, adds extra length that leads to difficulty in midline activities, such as the closure of zipper and bottoms, and also is unaesthetic which sometimes these reasons result in refusal of a prosthesis in wrist disarticulation (Figure 5).

Figure 5. Wrist disarticulation resulting in increased width that facilitate better prosthetic fitting compared to transradial amputation

- When 50% of forearm length is eliminated, only minimal forearm pronation and supination would be preserved (10). If transradial amputation is performed at the level of 8-10 cm proximal to the ulnar styloid, sufficient pronation and supination will be predicted (11) (Figure 6).

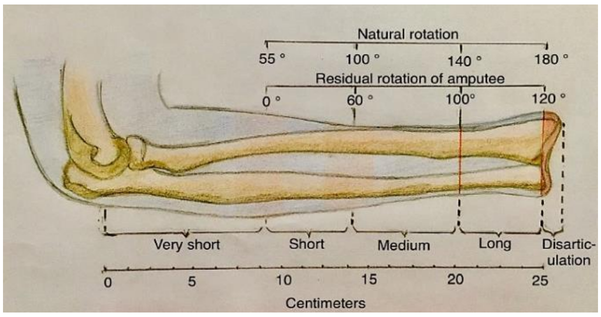

Figure 6. Relation between the amount of forearm amputation and residual forearm rotation

- At least 5 cm of the ulna from the tip of the olecranon process must be preserved for adequate prosthetic fitting (10). Then, elbow disarticulation should be avoided whenever possible.

Postamputation Care and Rehabilitation (4): Depression and anxiety are frequent in patients who have undergone major upper extremity amputations, so psychiatric consultation and therapy are essential issues in these patients, which should begin before the surgery and must continue after amputation. Suitable analgesics should be given to them for pain control, because painful extremity prevents patient participation in physiotherapy programs. Range of motion (ROM) exercises of the residual limb is recommended soon after the surgery. Occupational therapy, along with thermoplastic orthosis, helps to do some bimanual skills. Gradual compression provides a well-shaped stump for socket liner that can be done firstly at the end of the procedure with a well-molded casting in the operation room, followed by dressing and elastic bandage. The first month after the amputation is named Malone's "Golden Period", as the maximum compliance of the patients occurs in this time, and successful rehabilitation decreases significantly (about 60% decline) after the first month. The provisional prosthesis should be applied as soon as possible, and the final prosthesis when the edema resolves and the wound cures (4).

What Is the Difference between Orthoses and Prostheses?

Orthoses are the medical devices that control weakened or deformed body areas and are also used to correct bony and soft tissue malalignment and rehabilitation, whereas prostheses are used in limb loss as an artificial limb to enhance function and provide an aesthetic appearance.

- A passive prosthesis is a cosmetic terminal lightweight device that can be functional via stabilizing the objects or having work-specific designs. This prosthesis would be used in any amputation (Figure 7).

Figure 7. Passive prostheses

- Body-powered or mechanical (hook) prosthesis is lightweight and is the most frequent prosthesis in the upper extremity. Its price is remarkably lower than myoelectric prosthesis. This device controls scapular and humeral movement and consists of a simple system of metal cables, joint locks, and rubber bands. It is durable and needs little maintenance, so it is preferred by manual laborers. The main disadvantage of a body-powered prosthesis is its unaesthetic appearance due to the terminal hook. Similar to a passive prosthesis, it is usable in any level of amputation (Figure 8).

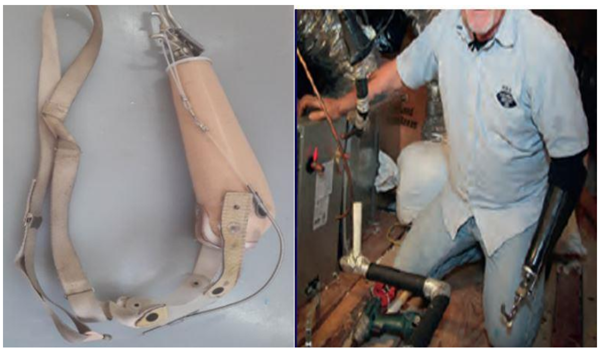

Figure 8. Body-powered or mechanical (hook) prostheses

- Battery-powered motors in myoelectric (externally powered) prostheses the patient to open and close the terminal device by activating agonist and antagonist muscles. This device provides more prehension strength (more than 30 pounds of pinch) than a body-powered prosthesis. It is very expensive, with a cost of about $100000 in the US. Moreover, myoelectric prosthesis requires interval maintenance and should be designed for recreational activities such as different sports, writing, eating, etc. Therefore, one person may need more than one myoelectric prosthesis during his activities. This device is preferred in transradial amputations (Figure 9).

Figure 9. Myoelectric prostheses

- The hybrid prosthesis consists of combined body-powered and myoelectric devices in one prosthesis. It provides a better function and is preferred in proximal levels of amputation (transhumeral amputation and shoulder disarticulations) (4) (Figure 10).

Figure 10. Hybrid prostheses

Krukenburg Procedure

A dead person has less burden to the society and family than a disabled one. The patients would have anxiety and depression after limb loss and also could not perform daily activities. The Krukenburg operation increases function of the patients to do most of their daily activities such as independent dressing with a minimal modification of clothing, holding large objects and then small ones, holding a pen to writing, and grasping a spoon and a glass for eating and drinking. Change of hand dominance is frequent in children. The rapid shift of hand dominance occurs during 4-6 months (12). The Krukenberg surgery requires a residual forearm length of more than 10 cm measured from the olecranon tip. The outline of the pronator teres should be determined on the volar side of the forearm, as it is the main adductor of both radius and ulnar bones. Longitudinal s-shaped skin incisions are designed on the volar and dorsal surfaces of the forearm that result in two musculocutaneous flaps with full-thickness skin coverage on the opposing sides of the ray. The adductor muscles consist of the pronator teres, flexor carpi radialis, and extensor carpi ulnaris. The abductor muscles of the ray are the brachioradialis, extensor carpi radialis longus and brevis, and flexor carpi ulnaris. Mainly, split skin grafts (SSGs) are applied to the outer surfaces of the rays (13, 14) (Figure 11).

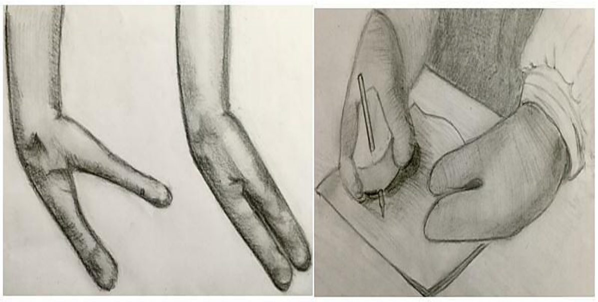

Figure 11. Krukenburg procedure that enhances the function of the patient

This procedure has a risk of functional failure if performed incorrectly. Western countries have a minimal trend to this surgery as a result of psychological rejection and anesthetic appearance of the bifid forearm. But the pincer-like grasp is more functional than an articulated prosthesis, unless be covered by an artificial hand (13). The majority of leg amputations achieve some independent functions when the patients use an appropriate prosthesis. Exclusive use of the healthy hand compensates for the action of the lost hand (13, 14). But amputation of both hands leads to the loss of touch, one of the five main senses (15). The radius and ulna are separated, making a pincer-like grasp that provides the patient a good pinch, grip, and sense. The soldiers who had bilateral blindness and massive bilateral hand damage with antipersonnel mines firstly underwent this procedure. Some of these patients could read Braille after Krukenburg surgery (16). Independent functions are more preferred than the aesthetic aspect in less-developed countries (13, 17). Resection of flexor digitorum profundus (FDP), flexor pollicis longus, pronator quadratus, abductor pollicis longus, and extensor pollicis brevis muscles decreases the size of the stump. Incision of the interosseous membrane should be done throughout its length along the ulnar border with care not to damage the interosseous vessels and nerves. The radiohumeral and proximal radioulnar joints provide motion. The opposing ends of the radial and ulnar rays should touch. The tourniquet is removed, and hemostasis is taken. The tips of both rays need sensate skins. The good function requires at least 10-12 cm opening between the pincers, which is achieved by detaching the interosseous membrane as proximal as possible. The pronator teres and supinator are the primary motors for radial ray, so they should be remained intact (18). Independent eating and drinking would occur during the 3-month postoperative period. All patients would do the simple dressing test successfully, and 75% regain some hand dexterity. This procedure is preferably performed only when the stumps are healed completely, as this decreases the risk of wound infection. If resources for hand prostheses are lacking, the Krukenberg surgery is suitable to gain some manual dexterity in bilateral hand amputation (18). It is also a good option in single hand amputation, and functional improvement is greater than a bilateral hand amputation, because the intact hand would be predominant, and the bifid hand acts as a supplement (19).

Replantation (Autograft)

- Epidemiology: The incidence is 2 per 100000 person-years. Men are involved six times more than women. Mostly, it is performed in 45-55 years of age and about 10% in children (age 0-14 years). The most common injured persons are factory workers (25%) and carpenters (15%).
- Replantation is indicated in thumb amputations at any level, multi-finger amputations, any amputation in the children, and amputations through the wrist, forearm, and elbow (20). Amputations distal to the insertion of the flexor digitorum superficialis (FDS) and ring finger avulsion injuries are relative indications (21). Any life-threatening injury which prevents prolonged anesthesia, chronic debilitating disease that limits rehabilitation, major psychiatric disease, dysfunction of the extremity from a previous injury or disease, severe contamination of the extremity, or prolonged warm ischemia of the amputated part are the absolute contraindications to upper extremity replantation. Single-digit amputations through zone 2 of the flexor tendon, multilevel segmental amputations, and ring finger avulsion amputations are relative contraindications (20, 22, 23). Physiological age, rather than chronological age, is considered in autograft with no predetermined age limit for replantation. Chronic medical diseases such as diabetes mellitus (DM) and chronic obstructive pulmonary disease (COPD) are not contraindications to operation; however, they need careful postoperative care (24). Today, the primary goal of replantation is the restoration of function, including skeletal stability, joint mobility, power, and sense (25). A more critical issue in replantation of hand amputation is restoring function as "survival without restoration of function is not success" (26).
- Replantation in incomplete and complete major amputations of the upper and lower extremity in children leads to 100% and 70% success, respectively (27). "Clean-cut" amputations by a knife (guillotine type) are a suitable indication for replantation, but limb loss with avulsion and crush has severe vascular, nerve, and soft tissue injury leading to higher infection rates, failure, and poor function. Among major autografts, amputations through the wrist joint result in better functions than the arm and forearm due to larger vessels and nerve size, easier bony fixation, the presence of only tendons, bone, ligaments (fewer muscles) that decreases the risk of metabolic disturbances and infections, suitable motor recovery because the forearm muscles are intact, and a short distance for regeneration of the repaired median and ulnar nerves (28, 29).
- The best method for bony fixation in wrist replantation should be determined according to individual circumstances, including primary arthrodesis of the wrist joint, proximal row carpectomy, or primary arthroplasty (30). Order of repair is bone, extensor, flexor, arteries, nerve, vein (BEFANV), and wound closure, respectively. Muscle necrosis begins after 4-6 hours of ischemia. Warm (20-25 °C) and cold (4 °C) ischemic times for the hand are 8 hours and 30 hours, respectively. Warm and cold ischemic times for the wrist and above are 6 hours and 12 hours, respectively (31). In the accident scene, all amputated parts in the field must be collected (regardless of the degree of contamination or quality of tissue) and wrapped in a gauze saturated with saline (not with water), placed in a plastic bag, then placed in

a bag of ice. The goal is to cool the part but avoid freezing the tissue. The patient's name is written on the bag and it will be transported with the patient to the hospital. Pressure dressings and elevation are used to control bleeding from the amputated stump, but tourniquets and ligation of blood vessels in the field should be avoided. In the emergency room, principles of global trauma management, including airway, breathing, and circulation (ABC), are performed. Amputated parts and amputated stumps are evaluated clinically and radiographically for surgical planning (Figure 12). Tetanus prophylaxis and broad-spectrum antibiotic are given. The team approach leads to more rapid and efficient replantation via simultaneous work on the amputation stump and the amputated parts. Debridement, dissection, and preparation begin before the patient enters the operating room.

Figure 12. Sharp wrist amputation of a 34 years old carpenter that the thumb remained attached to the limb

- In the major replantation, significant muscle burden exists, so appropriate hydration and fluid cardiovascular monitoring should be done by the anesthesiologist, and arterial repair must be performed as quickly as possible. If ischemia time is short, rapid osseous fixation is done first, followed by arterial reconstruction. If ischemic time is prolonged, an artificial arterial shunt should be applied first. A second venous shunt may be used to minimize the bleeding. Reperfusion of hand was done for 20 minutes for every hour of ischemia with shunt, and within this time, osseous fixation and repair of tendons and nerves are performed.

Bony Fixation

The pins (in the hand and wrist), plate (for the radius, ulna, or humerus), and external fixator (in the complex intraarticular amputation through the elbow) are utilized for bony fixation. Malrotation, angulation, and displacement should be assessed carefully, because poor bony alignment leads to functional failure of successful replantation.

Tendon Repair (Extensor and Flexor)

Extensor tendon repairs should be tight using the figure of eight techniques and nonabsorbable sutures. Flexor tendon repairs require locking two-core or four-core sutures, which are augmented with an epitendinous suture. In the zone 2 replantations, FDP tendon repairs are performed only to decrease the chance of stiffness, and there is no need to repair FDS tendon (20). Resection of FDS tendons decreases the risk of postoperative adhesion and stiffness. Primary repair of the deep flexor and extensor tendons of the fingers, the thumb tendons and the flexor carpi radialis, abductor pollicis longus, extensor carpi radialis longus and brevis, extensor carpi ulnaris, and flexor carpi ulnaris is done (32).

Arterial Repair

If spurt test (jet bleeding after the release of the arterial clamp) is inadequate, the artery is resected proximally to a less damaged vessel. Prior to excessive resection, topical vasodilators (warm saline, papaverine, and lidocaine) are used to relieve vasospasm. Three methods to arterial repair are: 1) primary repair, when there is no tension on the repair site, 2) "crossover" repair (i.e., the ulnar artery to the radial artery distally), that may be problematic during the next surgeries, and 3) interpositional reverse vein graft, when there is tension at the repair. It is necessary that the vein graft be applied at the reverse method or valvotomy by simple injection of saline into vein graft with an angio-catheter to prevent thrombosis from venous valves (20). Volar wrist veins and dorsal foot veins are similar in caliber to digital vessels, whereas saphenous veins are a better fit for vessels proximal to the hand (33).

Nerve Repair

During nerve repair, the nerve ends are cut back to intact fascicles (about 3-5 mm). Primary nerve repair is preferred, and bone shortening facilitates primary repair of nerve, vein, and artery without the need for the graft.

Vein Repair

Vein repair is the most technically demanding and important step in the replantation, which must be tension-free. Arterial repair before venous anastomosis results in venous engorgement and easier identification of the veins (20). Repair of both the radial and ulnar arteries and four or five of the largest dorsal veins is done through end-to-end anastomosis under 25 magnifications using 10/0 nylon. Primary repair of both the median and ulnar nerves is performed with an epi-perineural technique by 9/0 nylon (32) (Figure 13).

Figure 13. Replantation of wrist amputation immediately in the operation room. Pinballs (heparin lock devices) facilitate the surgeons to do the remaining surgery

Prior to releasing the clamps in the reperfusion phase, topical vasodilators (warm saline, lidocaine, and papaverine) are applied to the arteries and veins. The clamps are released on the artery first, but if a vein graft is used, the distal clamps are removed first, and then proximal clamps. The surgeon must await substantial engorgement of the distal veins prior to releasing the clamps on the venous anastomoses to prevent thrombosis from blood stasis. When all clamps are released, the digits are warm and moist. The digital tips assess for a Doppler signal, color, and turgor. A frequent finding is the lack of the Doppler signal in the operating room, but often an audible signal develops on the evening or next day after replantation. Skin closure should be loose (20).

Postoperative Care

The pediatric, major, or multiple-digit replantation requires frequent (hourly) monitoring after surgery. Bedrest for 3-7 days, sedation to control stress and resultant vasospasm and thrombosis, volar splint, topical heat (warming blanket, heat lamp, heated room), and daily aspirin are given. Dextran, heparin, or warfarin have no significant efficacy. The patient room must be warm with a temperature over 70 °F (21 °C). The dressing change is not performed for at least five days (Figure 14) unless in the case of severe bleeding from the wound, because the stress and discomfort from dressing change may cause vasospasm and thrombosis of the vessels.

Figure 14. Bony fixation of the hand (appearance of replanted wrist ten days postoperatively with normal color and capillary refill, but moderate swelling). Radiographs show reduction and pin fixation of the wrist (radiocarpal joints and carpal bones), first metacarpal bone and carpometacarpal (CMC) joint, and also fourth finger

Visual examination for monitoring the replanted digit is reliable, but a temperature probe confirms the clinical diagnosis, as a temperature of 32 °C or less in the replanted part indicates a poor prognosis. Early complications are infrequent; however, late complications are frequent, including stiffness of the finger, inadequate nerve regeneration, and bony malunion or nonunion. Tendon adhesion is the primary cause of finger stiffness that requires tenolysis (33). Postoperative functional outcomes compared to the uninjured hand are assessed by: (1) the patient's satisfaction, (2) flexor and extensor function of the thumb and fingers using the total active motion of each digit compared to contralateral digit, (3) thumb opposition, (4) sense in the median and ulnar nerve distributions using static two-point discrimination (2PD), and (5) daily tasks using objects of different shape and dimension to test fine and tripod pinch grip, span, grasp, and hook grip. The functional outcome with the replanted hands is satisfactory for daily tasks but is not functionally as good as the contralateral hand. Fasciotomies are not performed routinely except in the severe swelling and impending compartment syndrome (32). Forearm replantations result in good intrinsic hand muscles (34). Impaired functional recovery of the intrinsic and thenar muscles results from the prolonged ischemic time that causes intrinsic muscle contractures (irreversible damage) due to anoxia, causing metabolic lactic acidosis. Some surgeons modified the order of reconstruction in the forearm replantation as bone fixation, vein reconstruction, artery reconstruction, the release of the clamp, nerve repair, and muscle repair to decrease the cold ischemic time. In addition, arterial repair and reperfusion without venous reconstruction cause bleeding and swelling of the amputated part, and then venous repair should be done first, followed by arterial repair after induction of cold ischemia (35).

The dynamic splint is recommended in transmetacarpal (palm), wrist, and distal forearm replantation to prevent impairment or deformity of the intrinsic muscles. Replantation has significant functional, cosmetic, and psychological results that improve patient satisfaction and QOL (36). Amputation at or proximal to the wrist is termed macroamputation. Ischemia of the main muscles of the amputated part can produce local and systemic complications, both during and after macroreplantation (unlike digit replantation) (37). In proximal forearm amputation between the elbow joint and the insertion of the pronator teres on the radius, the bony ends are shortened (averagely 4 cm) to excise dead tissues and primary end-to-end soft-tissue repair. Repair of muscle bellies by gross epimyseal suture and reinsertion of avulsed tendons are done. Replantation of proximal forearm leads to useful recovery of extrinsic and intrinsic muscles in 40% and 10%, respectively. Return of protective digital sense occurs in 50% and 20% in the median and ulnar nerve territory. All patients are self-sufficient and independent in most activities of daily living (e.g., personal care, dressing, and eating). Objective results are poor, but patient satisfaction is obtained in 90% of cases, and the replanted limb is used as a help for activities of daily living. 10% of the patients would not be satisfied. Forearm avulsion results from a combination of crushing and tearing forces (twist and bending). Replantation in proximal forearm avulsion results in limited function, so replantation in avulsion amputation at the proximal forearm should be indicated only in motivated patients who want to keep the body integrity. Patients should be informed about the prolonged postoperative treatment, multiple surgeries, and poor function (38).

Recovery of muscle power and sense is assessed through the Medical Research Council (MRC) Scale (39) separately for extrinsic and intrinsic muscles and median and ulnar innervated zones. The questionnaire of Russell assesses subjective evaluation of function and patient satisfaction. Most vascular pedicles and motor branches to the 20 muscle bellies in the forearm originate within 10 cm from the antecubital crease, so neurovascular injuries of avulsion in this area are beyond repair, even when anastomosis or grafting of the main vessels and nerves restores circulation and innervation to the distal replanted part that leads to infections, muscle fibrosis, dysfunction, and poor sensory recovery. "Functional extremity" would be achieved in about 30% of replantation of the proximal forearm (40).

Failing Replantation

When slight changes in appearance, Doppler signal, or temperature are present, and vasospasm is suspected, and if vessel thrombosis has not occurred, nonsurgical treatments including analgesics, the release of compressive dressings, and environmental warming start, which provide limited improvement. Arterial ischemia due to thrombosis is uncommon and presents as pale, cold, poor capillary refill and pulseless limb that needs emergent re-exploration, resection of the artery's thrombosed segment, and vein grafting.

Venous congestion appears as blue-dark discoloration and swelling, which should be treated by elevation to heart level, the release of dressing and sutures, heparin-soaked cotton, or leeches every 4-6 hours applied to the nailbed for several days. Third-generation cephalosporin to cover *Aeromonas hydrophila (*a gram-negative bacteria that is normal intestinal flora in leeches) is prescribed. Blood transfusions are often needed after lengthy periods of leeches.

Expected Outcomes

- The survival rate of major replantation is 40%-80% (survival rates of replanted digits are 57% to 90%). Factors with a negative impact are the mechanism of amputation (crush), patient age (being worst in the first and seventh decades and best in the second decade of life), smoking history, level of amputation (zone 2 flexors, proximal limb loss), prolonged ischemic time, and severe contamination. More than one arterial anastomosis and more than one venous anastomosis increase survival rates. Functional outcomes [Disabilities of the Arm, Shoulder and Hand (DASH) scores] are better among replantation than amputation (20, 24, 31). The patients return to work with digit amputations on averagely about 2 and 4 months for injuries distal and proximal to the FDS, respectively (24), but arm replantations may need more than one year of rehabilitation and time off from work (21).
- Cold intolerance is common in all replantations (24) that is seen less in children (41). The digit's growth impairment does not occur in most children when the physis is not damaged (41). Protective sense is achieved in most of the above-elbow replantation, but the 2-point sense is rarely achieved (42). Useful control of the forearm, wrist, and hand improves with more distal amputations after replantation, and many patients will require tendon transfers for adequate elbow function (43).
- Forearm defects need a large vascularized flap. A groin flap (Figure 15) can be used, but a free flap is more suitable.

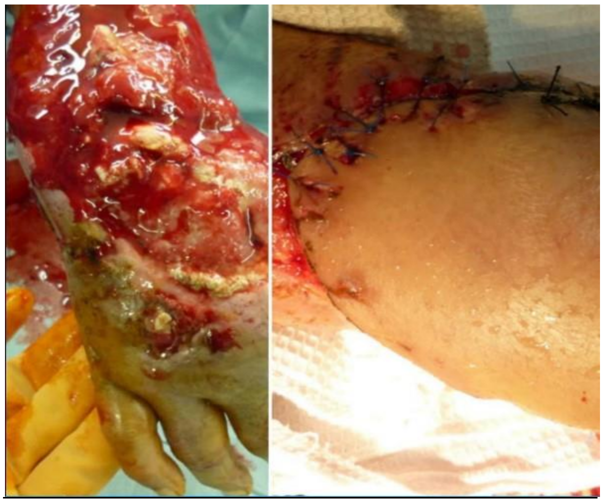

Figure 15. Forearm defect treated with a groin flap

Previous groin surgery or pelvic injury are contraindications of groin flap that periumbilical perforator flap can be used in these conditions (Figure 16).

A free gracilis muscle flap is appropriate, particularly when the fascia is sutured and resulted in 8 to 10 cm spread defect.

Figure 16. Forearm defect treated by the abdominal flap

The latissimus muscle free flap is used in large defects. The muscle (not fat) gives good coverage for tendon and joint gliding (Figure 17).

Figure 17. Elbow and proximal forearm defect treated with latissimus dorsi flap

An anterolateral thigh suprafascial perforator flap or a scapular or parascapular fasciocutaneous flap is designed when a large cutaneous flap is needed for tendon gliding. In the major muscle defects of the forearm consisting of the flexor or extensor compartments, an innervated functional free muscle transfer allows coverage and motor reconstruction in a single stage (44). Radial or ulnar artery forearm flap can be used proximally-based to cover defects around the elbow or distally-based for hand cover. Posterior interosseous artery flap also is used for elbow, forearm, and hand coverage, certainly to first web and metacarpophalangeal (MCP) joints (45). Lateral arm flap can be used up to 12 cm distal to the lateral epicondyle for proximal forearm defects (46).

Conflict of Interest

The authors declare no conflict of interest in this study.

Acknowledgments

We thank Mr. Alizadeh and the Red Crescent Society (RCS) of Tehran for providing samples of different prostheses.

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