ORIGINAL ARTICLE

Upper extremity replantation results in our series and review of replantation indications

Ayhan Okumuş, M.D.,[1] Aret Cerci Özkan, M.D.[2]

[1]Aesthetic, Plastic and Reconstructive Surgery Office, Bursa-*Turkey*
[2]Department of Emergency and First Aid, European Vocational High School, İstanbul-*Turkey*

ABSTRACT

BACKGROUND: Upper extremity amputations are usually not life-threatening, but they negatively affect the life quality of the victim. In addition to the functional disabilities of upper extremity amputation, disfigurements frequently cause psychological and social debilitations.

METHODS: Between 2007–2015, fourteen cases were admitted to emergency with total major amputation of the upper extremity. All cases were male (22–45 years of age. Mean age: 29.6). Replantation was applied to all except three cases with multileveled crush injuries.

RESULTS: All replantations were successful. Additional interventions were needed in four cases with replantation at elbow level and replantation at the distal arm level. The postoperative functional results were evaluated. The patient's overall satisfaction, the recovery of flexor and extensor mobility, the extent of the active motion of digits, the recovery of thumb opposition, active movements of wrist and elbow joints, recovery of sensitivity in the median and ulnar nerve, the ability of the surviving hand and/or forearm to perform daily works are all evaluated. The results were satisfactory in hand replantations. However, some ulnar nerve distal motor problems were encountered in three cases with replantation at elbow level, and one case with replantation at the distal arm level with a crush injury, acceptable and excellent results were obtained in other cases.

CONCLUSION: Despite the availability of prostheses, cadaveric upper extremity replantations, replantation of the native extremity is still the most appropriate treatment for amputated cases. However, surgeons should realize that the ultimate goal is not merely to save the viability of the extremity through replantation, but rather to preserve the life quality by improving the function.

Keywords: Arm amputation; forearm amputation; hand amputation; indication of replantation; replantation.

INTRODUCTION

Upper extremity amputations are usually not life-threatening, but they negatively affect the life quality of the victim. In addition to the obvious functional sequelae of upper extremity amputation, serious disfigurements frequently imply profound psychological and social debilitations.[1] The extremely important role of the hand in body image and sense of identity, as well as in work, relationships, activities has been confirmed by many authors.[2] Disabilities experienced in the daily life of individuals having congenital or acquired upper extremity loss and their requirements to several special rehabilitation tools is a well-known reality. Hands are one of the most crucial parts of our body in all our relationships with the external environment. Technologically powered prostheses may be satisfactory in cases with congenital absence of the upper extremity. However, it is not possible to talk about the same satisfaction in cases with acquired loss of the upper extremity. Even the best functioning prosthesis cannot be compared with a native extremity. Thus, in cases admitted to emergency clinics with amputation injuries, the best and acceptable restoration option is still the replantation of the native hand, albeit with its decreased and limited functional and sensational skills.

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Address for correspondence: Ayhan Okumuş, M.D.
Ihsaniye Mahallesi, İlknur Sokak, Bulvar 224 Sitesi, B: Blok, D: 10, 16120 Nilüfer, Bursa, Turkey
Tel: +90 224 - 243 43 43 E-mail: ayhan@ayhanokumus.com.tr

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MATERIALS AND METHODS

Between 2007 and 2015, fourteen cases were admitted to our emergency department with total major amputation of an upper extremity. All cases were male, whose ages ranged from 22 to 45 years with a mean age of 29.6 yrs. All of the amputations were work-related injuries. Three of them had severe multilevel crush injuries beginning from the shoulder level.

Three of them had an amputation at the distal arm level. One of these three cases with distal arm amputation also had crush injury at the forearm and fragmented fracture of the humerus. Two of these three cases had clean-cut injuries. One of these two cases also had a partial cut injury at an axillary level without any nerve damage but with an injury to biceps, teres major and latissimus dorsi muscles (Fig. 1b). In five cases, the amputation was between elbow and wrist and four cases had hand amputation with clear cut injuries (Fig. 1a-c). Replantation was applied to all of the cases except three cases having severe multilevel crush injuries beginning from the shoulder level. Either cold or warm ischemia times were appropriate in all cases. All cases admitted to an emergency clinic in three hours after injury, together with the physician practicing for that workplace. All of the amputates except one were reached to the hospital in properly prepared cold ischemic conditions. One case was admitted without proper cooling, but the warm ischemia time was appropriate in that specific case.

Surgical Procedure and Evaluation

In all cases, the preoperative preparation included prophylactic antibiotics, tetanus prophylaxis, iv. fluid supply to prevent volume loss, warming the patient to prevent hypothermia and vasoconstriction, Foley catheter application, and protection of possible decubitus areas. The exploration of the amputated part started before the patient is brought to the operating room. In most cases, there was plenty of time before the patient is transferred to the operating room for exploration of the amputated part.

In all cases with hand amputation, replantation was performed under general anesthesia with a tourniquet application. After debridement, the arteries, veins, nerves, and tendons were identified and tagged in both stumps. Signs of arterial damage was noted. Only loose small bone fragments of the carpus were removed, but all of the carpal bones were saved and internal osteosynthesis was performed using two or three K-wires (size 2.2 mm. 30 cm). In one case, with fragmented humerus fracture, an external fixator was used. Repair of all amputated structures, namely all tendons and

Figure 1. (a) Case-1: Wrist amputation. **(b)** Case 2: Distal arm amputation and axillary region soft tissue injury. **(c)** Case 2: Distal arm amputation. **(d, e)** Case 1: Early post-operative view. **(f)** Case 1: Post-operative 3rd year, full ekstansion of fingers. **(g)** Case 1: Post-operative 3rd year view, full flexion of fingers. **(h)** Case 2: Post-operative 5th year view, full flexion of fingers, view of biceps muscle fonction. **(i)** Case 1: Post-operative 5th year view, full flexion of wrist and fingers, abduction of thumb.

nerves, are done after providing both arterial and venous circulation by microsurgical vascular anastomoses (Fig. 1d, e).

In a case with additional soft tissue injury at the axillary region, all the muscles, bones and tendons at that region were also meticulously repaired after replantation. In replantations at the arm level, all the injured structures but specifically the triceps and biceps muscles were primarily repaired. At the forearm level, all the muscle repairs were executed with great care in order not to interfere with the blood circulation of the repaired vascular structures.

In hand replantations, Both the radial and ulnar arteries and four or five of the largest dorsal veins were repaired end-to-end under a microscope by using 8/0 ethanol. Neurorrhaphy of the median and ulnar nerves were also performed primarily using an epi-perineural technique with 8–9/0 nylon. None of the cases required the use of a vein or nerve grafts. After the skin closure, the affected limb was placed in a thermoplastic splint, which included the hand and forearm, and elevated for several days.

Postoperative Management

Postoperatively, broad-spectrum antibiotics, low dose Heparin to prevent deep vein thromboses, Dextran RMI 10 g (500 mL/day for 3 days), analgesic drugs (Flubiprofen) were applied for all patients. The K-wires were usually removed after 7–8 weeks. Physiotherapy was started on the tenth postoperative day and continued until the sixth postoperative month. Patients were encouraged to abstain from cigarettes, coffee, and tea consumption.

All preoperative, per-operative and postoperative principals were similar in replantations at elbow level except the need for fasciotomies and fixation of muscles instead of tendons. In cases with replantations at arm level, fasciotomies were performed in both flexor and extensor compartments of the forearm. In cases with replantations at the forearm level, the fasciae of both flexor and extensor compartments were released without skin release. Vessel, nerve, or tendon grafting was not applied in any of the replantation cases in our series.

Assessment

The two-point discrimination test was used to measure postoperative sensibility (Table 1). The

Table 1. Summary of sensory and functional results of replantation

Patient No-Age	Amputation level	Follow-up (year)	Satisfaction level	2-Point discrimination (Normal <6 mm)	Physical performance of the daily activities	ROM	Grip strength (kgf)	Pinch strength (kgf)	Criteria of chen
1 (22, L,ND)	Distal arm, Axillary soft tissue damage	12	High	14–16	Most of the daily activities	Good	22	7	I
2 (28, L, ND)	Distal forearm	2	High	10–12	Most of the daily activities	Good	24	6.5	I
3 (45, L, D)	Wrist	1	High	8	Most of the daily activities	Excellent	29	8	I
4 (24, L, ND)	Forearm	1	Very low-and Amputated	x	x	x	x	x	IV
5 (27, R, D)	Distal arm	3	Moderate	14–16	Holding, gripping, pinching only	Fair	14	6	III
6 (31, L, ND)	Distal Forearm	1	High	10–12	Most of the daily activities	Good	19	7	I
7 (25, R, D)	Wrist	2	High	9	Most of the daily activities	Excellent	30	10	I
8 (37, L, ND)	Proximal forearm	1	Moderate	12–14	Holding, gripping, pinching only	Fair	16	8	II
9 (32, L, ND)	Proximal hand	4	High	7	Most of the daily activities	Excellent	31	11	I
10 (29, L, ND)	Mid-forearm	5	High	10	Most of the daily activities	Good	23	9	I
11 (26, L, ND)	Wrist	2	High	8	Most of the daily activities	Excellent	29	8.5	I

L: Left; : Right; D: Dominant hand; ND: Non-dominant hand; ROM: Range of motion.

recovery of motor activity was evaluated based on the range of motion of each joint measured by a goniometer. Additionally, the total range of motions of the replanted fingers and thumbs was compared with the normal range of motions of the undamaged side and it is reported as a percentage of normal. The range of motions were rated as excellent (76% to 100%), good (51% to 75%), fair (26% to 50%), poor (1% to 25%), and fixed (0%) based on "The Guides to the Evaluation of Permanent Impairment".[3] The handgrips and pinch strengths were measured using a hand dynamometer and pinch meter. The Criteria of Chen was used[4] to evaluate the functional outcomes (Table 1).

RESULTS

All replantations were successful. The postoperative course of all four hand replantations and five replantations at elbow level and two arm replantations in our series was uneventful in the early postoperative period. In our series, fasciotomies were not performed in any hand replantation case. Infection, compartment syndrome, soft tissue necrosis, or any vascular complication requiring reoperation were not encountered.

All of the cases were followed up 3 yrs (1–12 yrs). Additional surgical interventions, namely tenolysis, muscle release, skin contracture release, and bone refixation, were needed in a case with fragmented humerus fracture and forearm arm replantation and also in other three cases with forearm replantations. Unfortunately, functional recovery has not been satisfactory in the case of humerus fracture and forearm crushed amputation injury. He had unbearable and incremental pain and subsequent amputation was performed distal to elbow level at the fourth month of replantation with the decision of the patient. In other replantation cases, additional surgical intervention was not required (Table 2).

The postoperative functional and sensory results were evaluated (Table 1). The patient's overall satisfaction, the recovery of flexor and extensor mobility of the thumb and fingers, the degree of the active motion of each digit, the recovery of thumb opposition, active motions of wrist and elbow joints, recovery of sensitivity in the median and ulnar nerve distributions, the ability of the surviving hand, forearm or arm to perform daily tasks are all examined together with physiotherapists (Table 1). The results were highly satisfactory in four of the hand replantations and three forearm replantation (Fig. 1f-i). However, minor ulnar nerve functional losses were observed in two distal arms, one distal forearm, and one proximal forearm level replantations. There were intrinsic muscle atrophies and related functional losses in their activities (Table 2).

DISCUSSION

The decision to attempt replantation of the severed part is influenced by many factors, including the importance of the part, level of injury, expected return of function, and mechanism of injury. Hand amputation through palm, hand amputation at distal wrist, any amputated part in a child, only sharp injuries more proximal arm are indications for major replan-

Table 2. The comparison of conservatively and surgically managed patients in grade IV

Patient No-Age	Amputation Level	Replantation procedure	Secondary procedures	Results
1 (22, L, ND)	Distal arm, axillary soft tissue damage	Primary, no greft, no shortening	No	Ulnar nerve distal motor insuficiency
2 (28, L, ND)	Distal forearm	Primary	No	Ulnar nerve distal motor insuficiency
3 (45, L, D)	Wrist	Primary	No	Satisfactory
4 (24, L, ND)	Forearm	Primary	Debridement, skin graft, bone refixation	Amputation
5 (27, R, D)	Distal arm	Primary	Bone refixation, skin contracture release	1-5 finger flexion insuficency, radial and ulnar nerve distal sensational insufficiency
6 (31, L, ND)	Distal forearm	Primary	No	Satisfactory
7 (25, R, D)	Wrist	Primary	No	Satisfactory
8 (37, L, ND)	Proximal forearm	Primary	Skin contracture relase,	ulnar nerve distal motor insufficiency
9 (32, L, ND)	Proximal hand	Primary	No	Satisfactory
10 (29, L, ND)	Mid-forearm	Primary	Tenolysis	Satisfactory
11 (26, L, ND)	Wrist	Primary	No	Satisfactory

L: Left; R: Right; D: Dominant hand; ND: Non-dominant hand.

tation. Amputations with severely crushed or mangled parts, multiple-level amputations are contraindications of a major replantation. Replantation in patients with multiple trauma or severe medical problems is a relative contraindication.[5] If an amputated forearm is exposed to hot ischemia, the limb may not be salvageable. So it is suggested that every team dealing with limb replantation should evaluate whether the amputated part is exposed to hot injury or not.[6]

The significance not only of the survival of the replanted extremity but also on functional superiority compared to a revision amputation has emphasized.[7] In addition, progressive improvement in sensation is ideal. In their comparison of patients undergoing either replantation or revision amputation with a subsequent prosthesis after major upper extremity limb trauma, Graham et al.[8] observed superior functional outcomes years after injury (average, 7.3 years) in patients who underwent replantation. Further, outcomes were even better in the replanted group when the intrinsic function was recoverable. Regarding success and durability of replantation, it is claimed that ''a 'bad hand' may be more functional than a 'good amputation' in the upper extremity''.[9] The factors related to good outcomes after replantation include the potential for long-term function, the patient's overall clinical status (including psychosocial wellbeing), the mechanism of injury, and the location of the injury. Specifically, better outcomes at 1 to 2 years have been observed in patients experiencing guillotine-type injuries near the level of the carpus. Similar long-term results were observed by Sugun et al.,[10] where avulsion or crush amputations near the elbow, as opposed to the wrist, were associated with a worse prognosis.

Presence of satisfactory results in distal level replantations, and presence of ulnar nerve motor and sensational problems in proximal level amputations in our series, parallel with the results of Sugun et al. However, it is interesting to note that, in the case with a clean-cut distal arm amputation, all the motor, and sensorial functions were regained except some degree of intrinsic muscle functions of the hand after replantation. In this specific case, we believe that his young age (22 yrs.), his confidence for a total recovery in the near future, his positive psychosocial mood were all helped him and of course, his good discipline in attending to all physiotherapy sessions was also highly effective in obtaining highly satisfactory results.

Good functional results can be achieved with replantation of injuries at the level of the hand at the wrist, and the upper extremity at the distal forearm. Replantation of the above elbow amputation should be attempted for elbow preservation, even though the chance for nerve recovery is low. If subsequent nerve regeneration is inadequate after upper arm replantation, revision amputation at the mid-forearm level can then allow for a below the elbow prosthesis. A below elbow prosthesis with a gravity activated grip is more functional than an above elbow prosthesis.[11]

It may be an unrealistic expectation to successfully replant severely crushed and mangled body parts. Avulsion injuries with traction along the neurovascular bundles create intimal tears and disruption of small branches to the skin. Small hematomas seen in the skin along the course of the neurovascular bundle result in the ''red line sign.'' This sign signifies such detrimental injury to the neurovascular bundle that replantation is often fraught with poor success.[11] Two other relative contraindications to replantation include multiple-level injuries and mentally unstable patients.

Even if not replantable, this amputated part can provide a valuable tissue source for reconstruction. The amputated part should be wrapped in a saline-moistened gauze sponge and placed in a plastic bag. The plastic bag should be sealed and placed on ice. The amputated part should not be placed directly on ice because this can result in a frostbite injury to the tissue.[12] The part should not be immersed in water. The recommended ischemia times for reliable success with replantation are 12 hours of warm and 24 hours of cold ischemia for digits, and 6 hours of warm and 12 hours of cold ischemia for major replants. Delayed and suspended replantations demonstrate results comparable to immediate replantation regarding graft survival and clinical outcome.[13] In our series, any delay in cold or warm ischemia time or in hospitalization and operation processes did not happen.

In replantaions at the arm level, brachial artery and vein, ulnar median and radial nerves are repaired with the written order. The muscles should be repaired unless they do not apply compression over anastomosed vascular structures. The skin should be approximated loosely. Skin grafts may be used if necessary. Especially in high-level amputations, some degree of muscle debridement sessions may be necessary with 48 hrs intervals. Arm level amputations may usually disturb biceps muscle functions and may necessitate pectoralis or latissimus muscle transfers. Skin grafting was not required in any of our eleven amputation cases. In two cases with arm-level amputation, muscles are repaired primarily without any related complication. In a case having multiple muscular injuries at the axillary level, the primary repair of these muscles did not cause any contracture, adhesion, or muscular atrophy. Despite the presence of both proximal and distal injuries of biceps muscle any postoperative problem is not encountered.

Replantation of hand amputations at the wrist level may sometimes necessitate bone shortening (e.g., proximal row corpectomy) to avoid nerve and vein grafts. Overall, the ulnar and radial arteries, four veins, median, ulnar, and superficial radial nerves are repaired and many tendons as possible. At least the four flexor digitorum profundus tendons, flexor carpi radialis, flexor carpi ulnaris, four extensor digiti communis tendons, extensor carpi ulnaris, extensor carpi radialis, extensor pollicis longus, and flexor pollicis longus should be performed. In general, replantations at this level can achieve very good results. In all of our cases, the brachial artery at

arm level or radial and ulnar artery and all ınjured nerves, muscles and tendons are repaired. The repair of flexor digitorum superficialis tendons is not spared during operation in our series. These are also totally repaired in all cases.

At postoperative recovery, warming the patient's room to avoid vasospasm, positioning the extremity at the heart level to minimize edema but not compromise arterial or venous flow is done. Anticoagulation is generally recommended. Sympathetic blocks have been described for high-risk replantations after crush avulsion injuries. Arterial insufficiency is the most common cause of replantation failure, accounting for approximately 60% of failures. Treatment of arterial insufficiency includes removal of potentially constricting dressings and tight sutures, decreasing extremity elevation to promote inflow with gravity, and sympathetic blockade. Finally, an early operative intervention can be considered if there is no improvement with the above measures. Reexploration to correct arterial insufficiency has been reported to be successful in 50% of return visits.[14,15] Venous congestion is a less common cause of replantation failure.[14,15] Venous congestion should be suspected with rapid capillary refill increased tissue turgor or bleeding of wound edges. Reexploration sequences for venous problems are similar to reexploration of arterial insufficiencies.

As the Chen classification[4] prepared for the postoperative evaluation of the cases with replantation of upper extremity assesses resuming the original work or another gainful work, performing daily activities, the range of motion at the affected joint and the recovery of sensibility, it is possible to use this classification to assess the success of the replantation in all cases having different amputation levels. That is why this classification is preferred in our series having amputations at different levels.

Developing technology with more sophisticated microscopes, new systems, such as spy fluorescent imaging,[16] more delicate micro-instruments, and gradually increasing the experience of microsurgeons, make it real to obtain more satisfactory results compared to the past. Obtaining very satisfactory functional recoveries even at high-level amputations by virtue of these developments encourage microsurgeons to expand the formerly established rigid criteria[5] of classical indications for replantation especially in young patients with clean-cut amputations because every individual successful replantation result thoroughly saves the wellness of one human's life and even the wellness of one family.

Conclusion

Despite the presence of high-tech prostheses and replantation possibilities from cadavers, replantation of the native extremity is still the best and optimum treatment for amputated patients, but this does not mean that all amputated parts should be replanted regardless of the condition and the level of the amputation. Clean cut injuries may lead to amplifying the surgeon's judgment toward replantation even in proximal levels as results of our series imply. Conclusively, surgeons should recognize that the ultimate goal is not merely to preserve all living tissue through nonselective replantation, but rather to preserve the quality of life by improving function and, secondarily, appearance.[17]

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ORİJİNAL ÇALIŞMA - *ÖZET*

Üst ekstremite majör replantayon sonuçlarımız ve endikasyonların tekrar gözden geçirilmesi

Dr. Ayhan Okumuş,[1] Dr. Aret Cerci Özkan[2]

[1]Ayhan Okumuş Estetik, Plastik ve Rekonstrüktif Cerrahi Ofisi, Bursa
[2]Avrupa Meslek Lisesi Acil ve İlk Yardım Bölümü, İstanbul

AMAÇ: İş ile ilgili el amputasyonları tek başlarına hayatı tehdit edici değildir. Ancak fonksiyonel sekellerine ek olarak oluşturduğu sosyal ve pikolojik sorunlar kişinin yaşam kalitesini olumsuz yönde etkiler.
GEREÇ VE YÖNTEM: 2007–2015 yılları arasında, 14 kişi üst ekstremite majör ampütasyonu ile acile başvurdu. Tüm olgular erkekti (ortalama 29.6 [22–45] yaş). Çok seviyeli ezilme yaralanması olan üç olgu hariç 11 olguya replantasyon uygulandı.
BULGULAR: Tüm replantasyonlarda başarı sağlandı. Önkol seviyesinden replantasyon yapılan iki ve distal kol seviyesinden replantasyon yapılan bir olguya ameliyat sonrası ek girişimler uygulandı. Ameliyat sonrası fonksiyonel sonuçlar değerlendirildi. Hastanın genel memnuniyeti, fleksör ve ekstansör hareket seviyeleri, her parmağın aktif hareket derecesi, başparmak opozisyon derecesi, el bileği ve dirsek eklemlerinin aktif hareketleri, medyan ve ulnar sinir traselerinde duyusal iyileşmesinın sonuçları, replante edilen elin ve/veya önkolun tüm günlük görevleri yerine getirebilirliği incelendi. Sonuçlar, el replantasyonlarında tatminkardı, ancak, proksimal önkol ve distal kol seviyesinde replantasyon yapılan dört olguda özellikle unlar sinir fonksiyonlarında distal motor minör fonksiyon sekelleri ile karşılaşıldı. Diğer hastalarda mükemmele yakın sonuçlar alındı.
TARTIŞMA: Gelişmiş protez seçenekleri, kadavralardan replantasyon olanaklarına rağmen, doğal ekstremitenin replantasyonu, ampute hastalar için hala en uygun tedavi yöntemidir. Bununla birlikte cerrahlar, nihai amacın sadece canlı dokuyu replante etmek değil, fonksiyon ve görünümü iyileştirerek yaşam kalitesini korumak olduğunu kabul etmelidir.
Anahtar sözcükler: El amputasyonu; kol amputasyonu; önkol amputasyonu; replantasyon, replantasyon edikasyonu.

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