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Results of Microsurgical Replantation and Revascularization Surgery of the Hand and Wrist

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Objective: The objective of this paper was to present the results of replantation and revascularization surgery of the hand or digit and to describe the factors associated with survival of the replanted and revascularized digit.

Methods: From January 1, 2005 to July 31, 2010, a retrospective review of the Microsurgery Unit Database was done to determine the number of patients referred to the Unit for amputations of the upper extremity. The injuries were classified by mechanism of injury (guillotine, crush, avulsion, and gunshot/blast), level of injury, and whether or not a vein graft was used. A total of 8 patients with 8 hand parts had replantation surgery and seven patients with 10 revascularized parts were reviewed.

Functional Outcome: Functional outcome was measured using the range of motion of the involved digit or body part using a finger or standard goniometer. Sensory recovery of the replanted or revascularized part was measured using the static 2-point discrimination test.

Results: A total of 86 patients from January 2005 to July 2010 suffered amputation or near amputation injuries that were referred to the Microsurgery Unit. Of these patients, 8 patients with 8 hand parts had replantation surgeries while 7 patients with 10 hand parts had revascularization surgeries. In total, there were 15 patients (14 males and 1 female) with an average age of 26.2 years old (range, 4-68 years old). The overall viability rate was 72.2% (62.5% for replantation surgery and 80% for revascularization surgery). The average follow-up of the patients who had a successful replantation procedure was 19 months (range, 3-48 months). Those who had successful revascularization procedures after partial or near amputation of the hand or fingers had an average of 7.3 months follow-up (range, 3-14 months).

Functional Outcome. Four of the 12 patients had no functional results because of no recovery yet was expected on recent follow-up. In all digital replantations, stiffness was present even after 6 months post replantation. Of the 5 patients who had successful replantation surgery, only 4 had functional results. The best results were from the through-wrist and through-palm amputations. Protective sensation was achieved in all tested patients.

Conclusion: Successful replantation and revascularization surgery mainly depend on the mechanism of injury. Crush injuries tend to have poorer prognosis compared to guillotine type injuries. Replantation and revascularization surgeries require intensive post-operative rehabilitation to maximize the functional outcome.

Key words: replantation, revascularization

Perhaps the epitome of microsurgery as applied in Orthopedics is the ability to re-attach a completely severed body part. This process entails re-attaching bones, tendons, muscles, nerves, arteries and vein. In amputations of the hand, replantation is often regarded as superior in terms of functional outcome compared to prosthesis replacement or any form of reconstructive surgery.[1] The first successful major replantation of a completely amputated limb was reported by Malt in 1966.[2] At the digital level, Komatsu and Tamai[3] first reported the replanatation of a completely amputated thumb using an operative microscope in 1968. Since then, various centers around the world, especially in North America, have established microsurgical centers in their respective areas. Aside from having a steep learning curve, replantation surgery by itself requires meticulous surgical technique, expensive surgical equipments and an experienced staff in charge of post-operative management.[4,5] Survival rates for replantation surgery worldwide range from 66 – 91% and several factors have been implicated in the survival of a replanted part.[5,6] In the local setting, there have been no reported results on the survival and functional outcomes of replantation or revascularization procedures of the hand.

The objective of this paper was to present the results of replantation and revascularization surgery of the hand or digit in the University of the Philippines-Manila, Philippine General Hospital and to describe the factors associated with survival.

Methods

From January 1, 2005 to July 31, 2010, a retrospective review of the Microsurgery Unit Database was done to determine the number of patients referred to the Unit for amputations of the upper extremity at the hand level. Amputations were classified into guillotine, crush/blunt, avulsion, and blast/gunshot injuries. We have defined replantation as reattachment of a completely severed part or parts, while revascularization surgery as the reattachment of a part that had an intact bridge of soft tissue but that needed vascular repair to prevent necrosis of the partially severed distal part of the hand. Inclusion criteria for the study were all patients where a replantation or revascularization surgery was done and had a follow-up of at least three months. Excluded were patients with incomplete data and a follow-up of less than three months.

Indications for replantation surgery are shown in Table 1. Patients were initially assessed by the orthopedic senior resident upon referral at the emergency room. The injuries were classified by mechanism of injury (guillotine, crush, avulsion, and gunshot/blast), level of injury, and whether or not a vein graft was used. Gunshot and blast injuries were not good candidates for replantation. The surgical technique for revascularization and replantation surgery was similar to previously reported studies.[7] Two teams were involved in replantation surgery. One team will explore the amputated part and identify relevant structures to be replanted, especially the arteries, veins and nerves. The other team will facilitate exploration of the extremity and find similar structures to prepare them for replantation of the amputated part.

In cases where the vessels could not be repaired primarily, vein grafts were used to bridge the arteries and veins. In finger replantations of < 1 mm arterial diameter, donor veins were usually harvested in the palmar area of the involved hand. If the arterial and vein diameters are > 1mm, we usually get the donor veins on the volar side of the forearm. In cases where there was a discrepancy in the diameters of the vessels, we split the smaller vessel to accommodate the larger diameter vessels. In all cases (except for patient 2), vein grafting was done on the arteries.

Table 1. Indications and contraindications for replantation surgery.

Indications for Replantation
Finger distal to the flexor sublimis insertion
Thumb
Multiple digits
Any part in a child
Through palm or wrist amputations
More proximal amputations (sharp cut only)
Contraindications for Replantation
Single digit amputations proximal to the flexor sublimis insertion
Severely crushed digit or hand
Severely contaminated amputated part
Multi-level amputations
Multi-trauma patient with life-threatening injuries+
Self-inflicted injuries in the psychologically disturbed+

+Relative contraindication

Postoperative

All patients were under sedation for the first 24-48 hours post replantation/revascularization and were maintained on NPO for the first 24 hours. General liquid diet was resumed on the second day, progressing to soft diet and solid food by the 3rd and 4th day post replant. Patients were placed in isolation rooms, whenever available. None were admitted to an intensive care unit, except for one child. All were monitored every hour using our standardized monitoring sheet for the first 48 hours. Monitoring was carried out by medical students and/or orthopedic residents. A pulse oximeter was continuously applied to the replanted finger or hand to monitor oxygen saturation (Figure 1). Progressive decrease of the O_2 saturation warrants immediate referral to the microsurgeon. Once the critical period of 48 hours has passed, they were monitored every 8 hours until discharged. The parameters monitored were

skin color, pulp turgor, surface temperature and oxygen saturation. Temperature was monitored in through-wrist or trans-metacarpal/trans-palm amputations/partial amputations. The temperature was compared to the adjacent normal skin. If there was a difference of > 2°C for two consecutive hours, the microsurgeon would be called in and the viability of the replanted part will be assessed for a possible trip back to the operating room for re-exploration of the vessels.

Figure 1. A portable pulse oximeter was continuously placed on the replanted finger or hand for monitoring. A progressive decrease or an O_2 saturation of less than 90% was indicative of anastomosis failure and the patient will be brought up to the operating room for re-exploration.

The only pharmacologic postoperative thromboprophylactic medication given to the patients was aspirin. All patients were given aspirin 325 mg OD for two weeks post replantation. In children, no thromboprophylactic medications were given.. Bleeding parameters such as PT (Protime) and PTT (Partial Thromboplastin time) were monitored every 3-4 days. Admission ranged from1-2 weeks post replantation/ revascularization procedure.

In cases where the digit or hand was at risk of failure, a bolus of 4,000 iu of heparin was given intravenously for two doses. In cases of possible venous failure, external bleeding by removal of the nail plate or a fish-mouth incision on the pulp was done. If these maneuvers were not effective, the patient would be brought up to the operating room for re-exploration.

All patients who had replantation and revascularization surgeries were formally referred to the rehabilitation department for restoration of finger or wrist motion at 2-3 weeks post operatively.

Outcomes Assessment

Primary Outcome: Viability of the Replanted Part

The replanted or revascularized part was considered viable if there was no necrosis on latest follow-up (range, 3-48 months).

Secondary Outcome: Function

Functional outcome was measured using two parameters: Range of motion and sensory recovery. The range of motion of the joints of the involved digit or body part was measured using a finger or standard goniometer. Sensory recovery of the replanted or revascularized part was measured using the static 2-point discrimination (2 PD) test. Sensory testing was done on the autonomous area of median and ulnar nerves.

Results

A total of 86 patients from January 2005 to July 2010 suffered amputation or near amputation injuries that were referred to the Microsurgery Unit. Of these patients, 8 patients with 8 hand parts underwent replantation surgeries while 7 patients with 9 hand parts had revascularization surgeries for incomplete or near total amputation (Table 2). In total, there were 15 patients with 14 males and 1 female with an average age of 26.2 years old (range, 4-68 years old). The overall viability rate was 72.2% (62.5% for replantation of complete amputations and 80% for revascularization of partial amputations). The average follow-up of the patients who had a successful replantation procedure was 19 months (range, 3-48 months; median, 12 months). Those who had successful revascularization procedures after partial or near amputation of the hand or fingers had an

average of 7.3 months follow-up (range, 3-14 months; median, 4.3 months). The overall average follow-up for the two groups was 12 months (range, 3-48 months).

Mechanism of Injury

For completely amputated fingers (n = 8), there were 4 crush injuries and 4 guillotine type injuries. For the revascularization procedures (n=7), there were 10 injured parts in 7 patients. For the injury type, there were 7 crush injuries and 3 guillotine type injuries with 3 patients having 2 revascularized parts.

Failure of Replantation Surgery

We had 5 failures: 3 on the replanted parts and 2 on the revascularized parts. All were digital injuries (4 digits and 1 thumb) (Table 2). The reason for the failure was shown in Table 4. Arterial thrombosis accounted for failures in 4 digits, while late arterial failure due to "artery only" anastomosis was the reason for one - no vein was available (patient 1). Vein graft was used in all except for patient 2, where a primary repair was done. Infection was present on day 2 on patient 3, which probably contributed to the arterial failure. Also in patient 10, we only anastomosed one artery and one vein. However, clinical examination of the failing digit pointed to an arterial failure. When the patient was brought up to the operating room, both arterial and venous repairs were thrombosed. None of the failing replants were salvaged during the return trip to the operating room. All five failures were difficult replantations: this meant that more than one revision anastomosis was done on the artery because of persistent thrombus formation at the anastomosis site. It is possible that all these fingers experienced what we call an ischemia reperfusion injury.[8-10] The average ischemia time for the digits with

Table 2. Demographic data of patients who had replantation and revascularization procedures.

Patient No. Replantation	Age	Sex	Mechanism of Injury	Level of Injury	Vein Grafting	Ischemia time (hours)	Final Result (Viability of Part)
1	4	M	Crush	Middle Finger (MP)	Yes	8	Failed
2	7	M	Crush	Small Finger (MP)	No	10	Failed
3	28	M	Crush	Thumb (MCPJ)	Yes	14	Failed
4	30	M	Guillotine	Thumb (IPJ)	Yes	9	Success
5	8	M	Crush	Small Finger (MP)	Yes	8	Success
6	29	M	Guillotine	Through Wrist (DR)	Yes	12	Success
7	23	M	Guillotine	Through Palm (TMC)	Yes	8	Success
8	17	M	Guillotine	Through Palm (TMC)	Yes	10	Success
Average Revascularization						9.87H Total	5/8 = 62.5%
9	44	M	Crush	Middle Finger(PP)	Yes	12	Success
10	32	M	Crush	Ring Finger (MP)	Yes	8	Failed
				Middle Finger(MP)	Yes	10	Success
11	7	F	Crush	Middle Finger(MP)	Yes	8	Success
				Index Finger (MP)	Yes	11	Failed
12	27	M	Crush	Middle Finger(PP)	Yes	6	Success
13	37	M	Crush	Middle Finger(PP)	Yes	12	Success
14	32	M	Guillotine	Wrist, Right (no bone)	Yes	8	Success
				Wrist, Left (no bone)	Yes	10	Success
15	68	M	Guillotine	Distal Radius (DR)	Yes	10	Success
						11.7H Total	8/10 = 80%
Grand Total							13/18=72.2%
Average						12.25	

PP - proximal phalanx; MP - middle phalanx; TMC - transmetacarpal; DR - distal radius; IPJ - interphalangeal joint

failed replantation/revascularization surgery was 10.4 hours, while those with successful/viable replanted/ revascularized part were 9.5 hours.

Primary Outcome: Viability of the Replanted Part

Replantation Group

In the replantation surgery patients (n=8) with 8 replanted parts, the overall success rate was 62.5%. In patients with crush injuries, the success rate was only 25% (1 of 4 replanted parts), while the success rate for the guillotine type amputation was 100% (4 of 4 replanted parts).

Revascularization Group

In the revascularization surgery, there were 7 patients with 10 revascularized parts; the overall success rate was 80%. In patients with crush injuries (7 revascularized parts), the success rate was 71.4% (5 of 7 revascularized parts). In the guillotine type injuries, the success rate was 100% (3 of 3 revascularized parts).

For both replantation and revascularization groups, in terms of mechanism of injury, the success rate for crush injuries was 45% (5 of 11 parts), and for guillotine type injuries, 100% (7 of 7 parts). In crush injuries, the vessels for repair are usually damaged and prone to thrombosis.

Secondary Outcome: Function

The functional outcome of successful replantation and revascularization procedures in terms of sensory recovery and range of motion is summarized in table 3. Thirteen parts in 12 patients were viable after replantation and revascularization surgery. Of the 13 viable parts (in 12 patients), only 8 patients had sensory recovery as of latest follow-up. In two patients, the range of motion was not tested. In all digital replantations, stiffness was present even after six months post replantation. The best results were from the through wrist and through-palm amputations. Protective sensation was achieved in all tested patients (8 patients) (Table 3). All patients with limited range of motion had crush amputations.

Table 3. Functional outcome of replantation and revascularization procedures.

Patient No.	Age	Sex	Location	Sensory Recovery	Range of Motion	Follow-up (months)
4	30	M	Thumb	Not tested	IPJ: 0-20° thumb flexion	5
5	8	M	Small Finger	Light touch present	PIPJ: 10-25° DIPJ:30-50°	12
6	29	M	Through Wrist	Median (6mm) Ulnar (5mm)	Wrist: 0-50° flexion Wrist: 0-45° extension	48
7	23	M	Through Palm	Median (8mm) Ulnar (10mm)	Wrist: 0-30° flexion Wrist: 0-25° extension	28
8	17	M	Through Palm	Not tested	Not tested	3
9	44	M	Middle Finger	12 mm 2PD	Ankylosed at 40° flexion	8
10	32	M	Middle Finger	Not Tested	Ankylosed at 20° flexion	5
11	7	F	Middle Finger	Light touch present	Ankylosed at 50° flexion	6
12	27	M	Middle Finger	12 mm 2 PD	PIPJ: 20-50° flexion	3
13	37	M	Middle Finger	12 mm 2 PD	Full Range: DIPJ and PIPJ	12
14	32	M	Wrist, Both	Median nerve (8 mm 2PD) Ulnar nerve (8mm 2PD)	Full Range: DIPJ, PIPJ, MPJ (for both wrists)	14
15	68	M	Distal Radius	Not tested	Not tested	3
Average						12.25 months

IPJ - interphalangeal joint; PIPJ - proximal interphalangeal joint; DIPJ - distal interphalangeal joint
2PD - 2 point discrimination test

Case

Patient 1. A four-year old male was taken to the emergency room for a traumatic amputation at the level of the proximal interphalangeal joint (PIPJ) of the middle finger of the right hand. His hand got caught in the escalator of a local shopping mall. The amputated part was crushed and contaminated with grease (Figure 2). This alone is a relative contraindication for replantation, but since this was a child, replantation was attempted. A single artery was successfully anastomosed, however, no vein was found to be viable for anastomosis distally. External bleeding with removal of the nail and a fish mouth excision of the pulp was done for venous drainage. However, congestion still occurred and after 5 days, the finger was necrotic. Amputation was done at the PIPJ level and the child was fitted with finger prosthesis after 6 months.

Figure 2. Patient 1. A 4-year old male with amputation of the middle finger of the right hand. The middle finger was caught in the escalator and was crushed on presentation at the emergency room (upper left). A replantation was attempted but no vein was available for anastomosis (upper right). The finger necrosed after five days even with external bleeding from nailplate removal and fishmouth incision of the pulp (lower left). A prosthesis was fitted after completion amputation after six months (lower right).

Patient 7. A 23 year-old male was referred to the Microsurgery Unit for a complete amputation through the wrist due to a paper cutter. The hand was only held by a very thin strip of skin (Figure 3). After replantation, very good sensory recovery was achieved as well as good range of motion of the hand, even though an adduction contracture of the thumb was present.

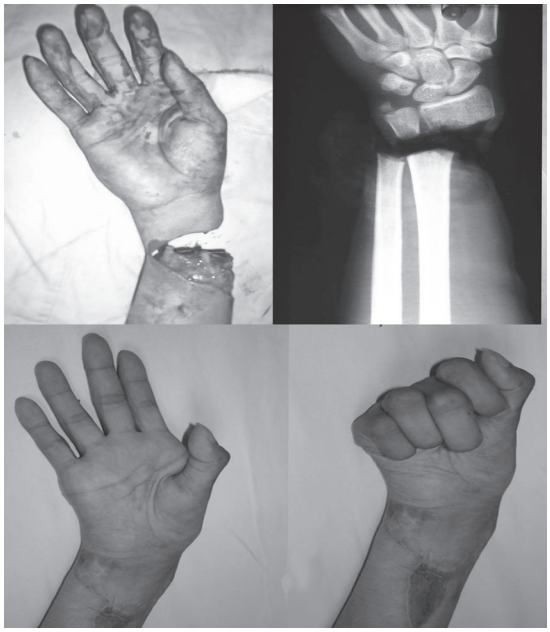

Figure 3. Patient 7. A 23-year old male with a complete amputation of the right dominant hand at the wrist level (upper left and right). Four years after replantation, the right hand was functioning very good (lower left and right)

Patient 5. An 8 year-old male sustained a complete amputation of the small finger at the level of the PIPJ due to a crush injury (Figure 4). In this case, a single artery and two veins were anastomosed. Ten months post-op, digital stiffness was apparent because of lack of physical therapy. Sensory recovery was however restored.

Figure 4. Patient 5. An 8-year old male had a complete amputation of the small finger (left). Replantation was successful, however, stiffness of the proximal interphalangeal joint was evident (right).

Discussion

The decision to replant a body part was based on many factors. Since not all hand or finger amputations were candidates for replantation, certain indications have emerged to help the surgeon and patient decide on the proper course of action (Table 1). However, there was a strong consensus among surgeons that replantation should be tried, especially in children.[6] Success rates for replantation worldwide ranged from 70-90%.[11-14] The success rates or viability rates of the replanted part doesn't always guarantee a successful functional outcome. A good functional outcome after replantation surgery of the hand was reported to range from 18% - 44%.[15-17]

The success rate of replantation surgery in this tertiary institution was lower at 63% compared to world literature of 75% in a recent meta-analysis.[5] The author also reported that crush injuries had a 68% viability rate after replantation, as opposed to 45% reported in this study. The success rate for guillotine-type amputations in this study was 100%. Sensory recovery with protective sensation was achieved in all examined patients. However, range of motion was limited in five patients who had crush amputations and in flexor zone 2 areas. Close follow-up with the physical therapist is mandatory to achieve a good functional outcome, especially in crush and zone 2 amputations.

Several factors were found to be associated with successful finger or hand replantations. Among these factors were mechanisms of injury: crushed or avulsed digits are more likely to fail compared to clean cut injuries, smoking history, history of diabetes, distal replantations, ischemia time greater than 12 hours, male sex.[5] In this case series, all failures in replantation and revascularization surgeries were arterial in origin except for one. Prolonged ischemia was usually the cause in these cases. Ischemia reperfusion injuries can occur from prolonged ischemia and are caused by a variety of factors. However, they revolve around on the production of O_2- free radicals that mediate damage to the endothelial cells.[8-10] Damaged endothelial cells will lead to the production of inflammatory mediators. This usually occurs within minutes of reestablishment of blood flow. After this, there will be adhesion of leukocytes to venules that will produce eventual vasoconstriction. The blood flow rate will then slow down and intravascular thrombosis will occur.[10] In this case series, the average ischemia time for failed replantation/revascularization procedures was 10.4 hours, while those with successful replantations was 9.5 hours.

The failure of anastomosis was usually evident at the time of anastomosis such that in all failures of replantation, several attempts of arterial anastomosis were made. Perhaps what should have been done was use a longer vein graft and resect a generous part of the damaged artery, thereby bypassing the zone of the injured artery. In some cases, generous bone shortening should have been employed. Although bone shortening was done, even as much as 1-1.5cm of bone shortening will afford approximation of arteries and veins. In the cases of partial amputations in patients 10 and 11, both patients had two finger involvements, connected only by the flexor tendon. In retrospect, again, the bone should have been generously shortened. In patient 1, where arterial anastomosis was successfully done, no vein was available such that external bleeding was employed. However, even external bleeding was not sufficient, eventually congestion ensued and the digit did not survive. Artery-only anastomosis for finger replantation has been reported[18] to have success rates of 86.67% (13/15). However, in these cases, the authors employed anticoagulation therapy of heparin (8000 to 16,000 IU/d), urokinase (240,000 IU/d), prostaglandin E1 (120 ug/d), and low-molecular-weight dextran (500 mL/d) intravenously.

At present, replantation and hand revascularization surgeries are mostly concentrated on specialized centers with experienced staff and adequate equipment capable of carrying out such procedures. In the Philippines, there are perhaps only a few centers capable of such procedures. The unavailability of both equipment and personnel has been the reason why such procedures are not routinely available in most tertiary centers. However, non-microsurgery replantation of the fingertips has been reported with conflicting results. Arata, et al.[19] used the non-microsurgery replantation in fingertip amputations with the palmar subcutaneous pocket technique in 16 fingers with 13 fingers surviving completely and 3 fingers with tip necrosis that were managed with daily

dressing changes. Similarly, Lee, et al.[20] used the same principle in adults (29 fingertips) but used an abdominal pocket. Sixteen (16) fingers survived completely, 10 fingers had partial necrosis, while 3 fingers had either total or near total necrosis. However, Muneuchi, et al.[21] had 7 amputated fingers treated with the palmar pocket technique with only one finger surviving completely. Muneuchi, et al.[21] suggested that this technique should be done only in children. We have very limited experience with this technique with only one successful case done. In order to increase successful outcomes in terms of viability and function, we suggest the following: Proper patient selection is needed. Inadequate post-replant rehabilitation will likely result in poor functional outcome, especially in crush and zone 2 single digit amputations. The decision to do replantation surgery on single digit amputations should be well discussed with the patients. If the results of replantation will be poorer compared to an outright amputation, then replantation surgery should not be done. This is especially true in single, zone 2 amputations of the index finger.[16] Amputations at the metacarpal or wrist level will likely result in good functional outcome. This is why it is important as much as possible to do replantation and revascularization procedures in these types of amputations. Use vein grafts liberally especially in crush amputations to bypass zones of injury. Shorten bone for primary vessel repairs, especially in cases of guillotine-type amputations.

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