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Case Report

Rehabilitation of a patient following hand replantation after near-complete distal forearm amputation

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ABSTRACT

Study design: Case report.
Introduction: Reports of comprehensive rehabilitation following hand replantation are limited.
Purpose of the study: To describe hand therapy of a patient following hand replantation.
Methods: Right hand dominant 55 year-old male assessed 9 days following left hand replantation to treat distal forearm amputation. Patient presented with dorsal blocking orthotic. Initial status: AROM digits and thumb 0–20° extension, 0–40° flexion; absent light touch sensation; 0–1/5 hand strength. Patient underwent 70 hand therapy sessions over 13 months focusing on A/PROM, therapeutic exercise, neuromuscular re-education, and modalities to address functional limitations.
Results: Hand therapy discharge status: AROM digits and thumb form composite fist, thumb opposition to digit 3, light touch sensation (monofilament) 4.03 (digits 2, 4) and 4.17 (digits 1, 3, 5); 3– to 4–/5 hand strength.
Discussion: Hand therapy allowed for near complete functional return of the hand following replantation.
Conclusion: Comprehensive Hand therapy aided restoration of adequate sensation and strength for functional use of the replanted hand.
Level of evidence: 4

Introduction

Loss of a limb can have devastating ramifications to an individual's social, physical and emotional well-being, severely affecting a person's activities of daily living (ADLs), employment skills, and recreational activities.[1] Replantation is a surgical procedure utilized to reattach a limb that has been amputated, which involves reattachment of the anatomical components that have been severed, including the anastomosis of the arterial in-flow, as well as the venous return in most cases.[2] Advances in modern microsurgical technology and a clearer understanding of tissue healing in response to trauma have resulted in a reasonably predictable success rate with replantation of an amputated extremity.[3] The success of digital replantation is well documented. Since successful hand and distal forearm replantation is less common, there are only a small series of published case studies.[3,4] The available research regarding hand replantation focuses on surgical outcomes, stating favorable functional outcomes are possible with appropriate surgical and postoperative rehabilitative care, despite a generally decreased return in sensibility and a significant amount of cold intolerance of the hand.[1] The hand replantation literature does not discuss in any detail however, the intense, lengthy rehabilitation involved in achieving successful functional outcomes following surgery. Therefore, the purpose of this retrospective case report was to describe the comprehensive hand therapy treatment associated with the rehabilitation of a patient following hand replantation surgery after traumatic near-complete distal forearm amputation.

Methods

Patient information

The patient was a 55 year-old right hand dominant white male who sustained a near complete amputation of his left distal forearm after his sleeve was caught in a Miter saw. He was admitted to a local hospital and was immediately flown to a specialty hospital for replantation by an orthopedic hand surgeon. He had a past medical history of coronary artery disease, coronary artery bypass graft surgery, hypertension, jaundice from alcoholism (quit 26 years prior to injury), and depression.

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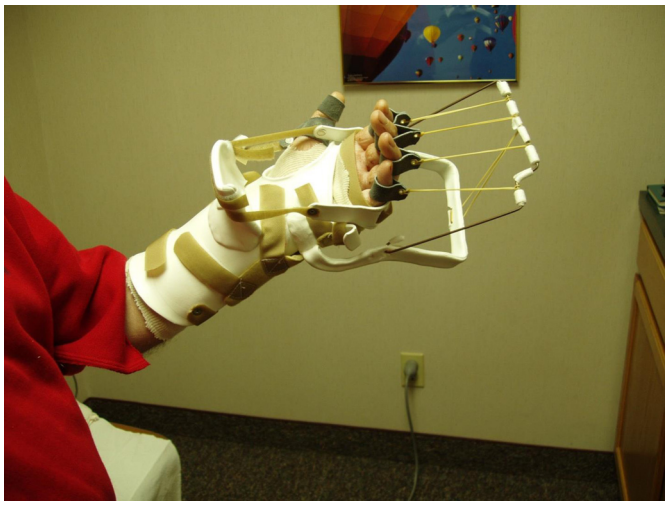

Fig. 1. Initial presentation of patient in orthosis.

Prior to the accident, the patient lived with his wife, was employed as an engineer and was independent with all ADLs. The patient reported having a strong desire to return to work and his previous independent living status. The patient provided informed consent for the retrospective review and subsequent professional presentation of his treatment case.

Replantation surgery

The replantation included open reduction and internal fixation of the ulna (with six-hole plate) and radius (with eight-hole plate). This was followed by repair of all injured tendons: flexor digitorum profundus (FDP) 2–5, flexor digitorum superficialis (FDS) 2–5, flexor pollicis longus, flexor carpi radialis, flexor carpi ulnaris, palmaris longus, extensor carpi unlaris, extensor digitorum 2–5, extensor digiti minimi, extensor pollicis longus and brevis, abductor pollicis longus, extensor carpi radialis longus and brevis. The radial and ulnar arteries were repaired, followed by repair of the median, ulnar, radial (superficial branch), and dorsal ulnar sensory nerves. The basilar vein was repaired, and a 3 cm vein graft repair was made of the cephalic vein. Closure was achieved with advance of skin flap and the use of a skin graft. Total tourniquet time of the surgery was 2 h and 45 min.

Hand therapy examination

The patient initially presented to hand therapy nine days post-surgery wearing an orthosis (fabricated by an orthotist in consultation with the treating physical therapist who was a certified hand therapist [CHT]) and sling for his left wrist and shoulder, respectively (see Fig. 1). The orthosis placed the hand in mid-position to protect the flexor and extensor repairs and prevent early clawing. The patient reported constant pain at a level of 2/10, "pins and needles" and a burning sensation over the palmar and volar aspect of his left hand. The patient managed his pain with over-the-counter Tylenol® due to experiencing adverse side effects with prescribed pain medication. After the replantation, the patient was limited with all ADLs utilizing his left hand. The patient reported requiring assistance from his wife with most ADL activities (e.g., bathing, dressing, eating).

The left extremity was first carefully palpated for tenderness and inspected for temperature, color, odor, unusual drainage, and edema. There was minimal edema noted in the digits, and there were no signs of tissue rejection (rash, red discoloration, or swelling). Active range of motion (AROM) was assessed for the hand (measures obtained in the orthosis), and shoulder (see Table 1). The orthosis was monitored to insure correct fit, observing for any pressure points. Formal sensory evaluation was not performed since gross sensory assessment demonstrated an insensate hand, and due to nerve injury and repair, sensation distal to the wrist would not be anticipated for 3–6 months. Resistive strength testing of the hand and wrist were contraindicated secondary to the surgical repair of the tendons. Rehabilitation potential for this patient was fair + to good, based on factors that delay healing such as advanced age, severity of trauma with the initial amputation, and past medical history.

The patient was initially seen in the clinic twice weekly; a plan of care was developed following Kleinert Institute Rehabilitation Treatment Guidelines for Distal Forearm to Transmetacarpal Level Replant/Transplant (see Table 2). The plan of care consisted of gentle soft-tissue mobilization (STM), debridement of volar forearm wound, scar massage, electrical stimulation (ES), ultrasound (US), therapeutic exercise, neuromuscular re-education, and a home exercise program (HEP). Primary treatment rationale was to promote active motion of the digits without placing the tendons at risk for gapping and/or rupturing.

Intervention

The patient was treated in hand therapy over a 13-month period, with a total of three episodes of care due to new surgical interventions (see Fig. 2). The second episode of care, which began seven months post-replantation, followed a second surgical procedure to address distal radius non-union with wrist stiffness, using a bone graft and skin graft extension. The third episode of care occurred approximately 12 months post replantation following a

Table 1
Active range of motion of left upper extremity

Left UE	EOC1 initial	EOC1 discharge	EOC2 initial	EOC2 discharge	EOC3 initial	EOC3 discharge
Digit AROM	30–40° of PIP flexion; −20° PIP extension	Lack ½ inch from PFC for full composite flexion	Full comp flex; lacks 15° PIP composite extension	Full composite flexion	Full flex, index lacks ½ inch flex PFC; lacks 15° PIP ext	Full composite flexion
Wrist flexion	25°	25°	25°	40°	30°	60°
Wrist extension	10°	30°	30°	45°	20°	45°
Radial Deviation	5°	15°	0°	5°	5°	20°
Ulnar Deviation	10°	30°	15°	25°	20°	22°
Supination	80°	80°	80°	85°	75°	75°
Pronation	80°	80°	70°	80°	65°	80°
Shoulder flexion	130°	165°	170°	170°	170°	170°
Shoulder abduction	130°	170°	165°	170°	170°	170°
Shoulder IR	70°	85°	85°	85°	85°	85°
Shoulder ER	65°	80°	80°	85°	85°	85°

EOC = episode of care; AROM = active range of motion; PIP = proximal interphalangeal joint; PFC = proximal flexion crease; IR = internal rotation; ER = external rotation.

Table 2
Kleinert Institute Rehabilitation Treatment Guidelines

Goals of post-op therapy: Distal forearm to transmetacarpal level replant/ transplant
1. Proper hand positioning: wrist extension (15°–30°); intrinsic plus/thumb abducted palmarly and radially.
2. Control pain: TENS, elevation, gentle controlled exercises. Check for any neuritis resulting from axillary block, if used.
3. Control swelling: TENS, elevation (level dependent on arterial versus venous compromise; specify in notes), gentle controlled exercises.
4. Exercises to encourage tendon gliding while protecting repairs. Exercises to maintain full range of motion in all joints that can be safely mobilized.
5. Patient and family members to become accomplished with all exercises and orthotic wear.
6. Protect extensors for as long as needed to prevent any lag.
7. Do not allow full MP extension until intrinsic have either tightened enough or have recovered enough function to prevent clawing.
8. Keep part warm, avoid smoke and caffeine for a minimum of 3–4 weeks.
9. Educate about sensory precautions.
10. Dominance re-training if dominant hand is affected.
Overall goal: Maximize motion and function while protecting repaired structures during their healing process.

third surgical procedure consisting of tendon transfer, neurolysis, and tenolysis due to limited recovery status post replantation.

First episode of care

The first episode of care (EOC1) covered five months, with the patient seen twice weekly in the clinic. Rehabilitation during EOC1 consisted of AROM, PROM, pain management, edema control, orthotic intervention, and an intense HEP. Following formal initial evaluation, hand therapy treatment at the initial session consisted of gentle active exercises such as place-hold exercises performed in slight flexion, moderate flexion, and maximal flexion with tendon gliding exercises (TGEs). The exercise protocol was approved by the hand surgeon as being within the tolerance of the repaired tissues. Tendon gliding exercises were conducted in table-top, hook fist, and straight-tip fist positions. For the HEP, the patient was instructed to perform gentle passive exercises for each joint four to five times per day, while active exercises were to be performed hourly, five to ten repetitions. These exercises were derived from those conducted in hand therapy sessions, and the patient demonstrated successful in-clinic performance prior to conducting the exercises at home. At the second visit, wound check revealed bruising within a 2 × 2 cm area at the radial volar aspect of his left wrist. Wound check on the third visit revealed green necrotic tissue, and wound care commenced and continued until closure four weeks post-op.

In the second postoperative week, joint blocking exercises were initiated with the purpose of isolating the glide of the FDP and FDS to prevent adhesions within the tendons. Gentle PROM and stretching exercises were incorporated when joint stiffness was present; caution was taken to avoid vigorous stretching that could result in increased pain and inflammation, thus impeding recovery. Edema control was utilized to prevent restrictions in ROM; this consisted of hand elevation above the heart with ten repetitions of active fisting performed hourly, and Coban® wrap applied distal to

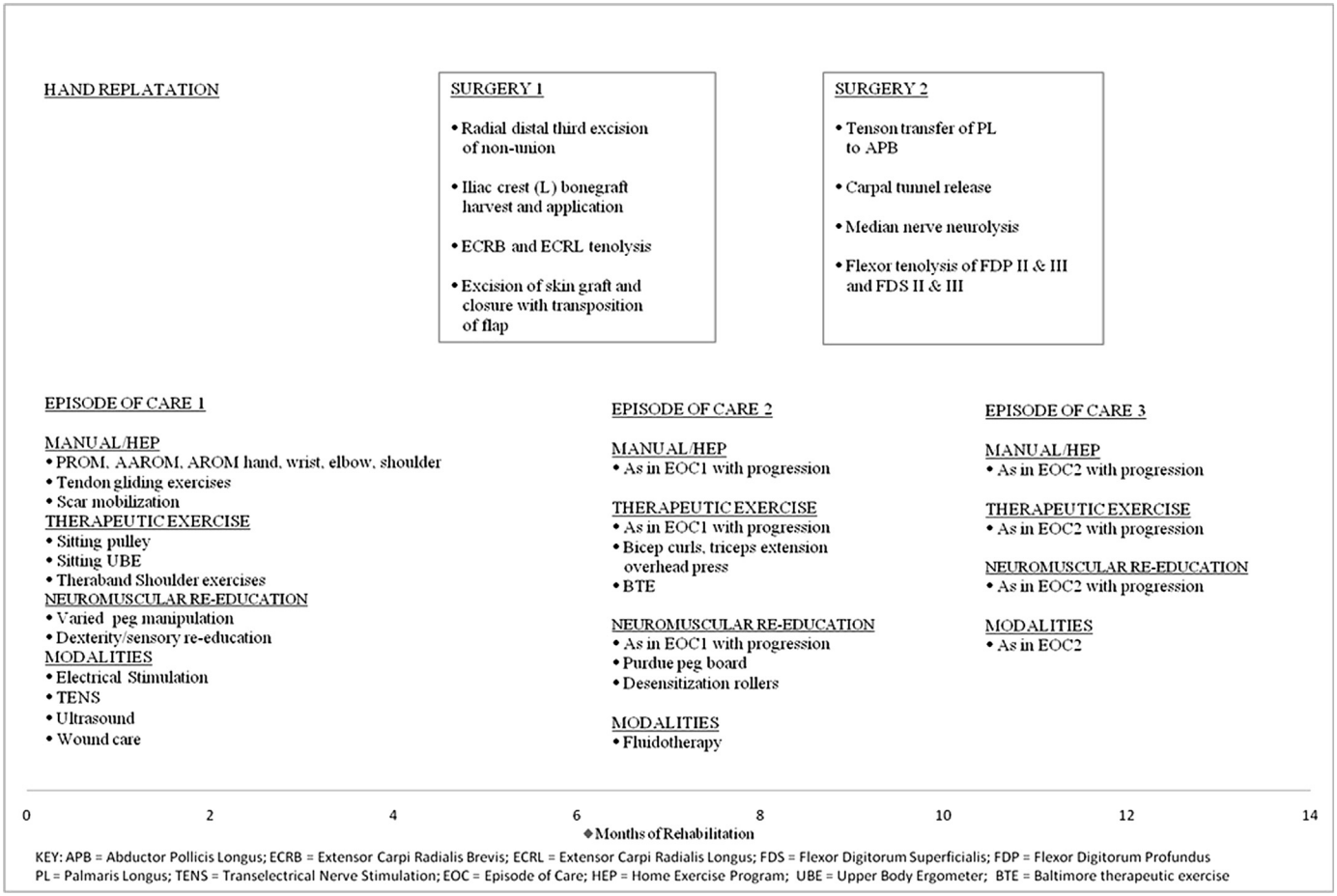

Fig. 2. Timeline and summary of case.

proximal to each digit and hand, worn 24 h a day with the exception of removal for bathing and exercise. Postoperative discomfort was eased with a trans-electrical nerve stimulation unit to the forearm.

A crane outrigger orthosis was fabricated at the specialty hospital two weeks status-post replantation. The orthosis positioned the wrist in slight extension (15°–30°), MCP joints in 50°–70° flexion with adjustable MCP joint block, PIP and DIP joints at 0° by light dynamic extension, and thumb in palmar abduction with some extension (between full extension and abduction).

Four weeks post-surgery, PROM exercises (all ten repetitions with 10 s hold) were initiated to improve left shoulder flexion, abduction, internal/external rotation, elbow flexion/extension, forearm supination/pronation, and gentle wrist flexion and extension. Active exercises for the hand were also gradually progressed.

Two and a half months post-surgery the patient was weaned out of the dynamic orthosis and transitioned to wearing an anti-claw orthosis throughout the day. In addition, he was also fitted with a functional position night orthosis, positioning the MCP joints in flexion, the PIP and DIP joints in extension, and the thumb in palmar abduction. The treatment rationale for this orthosis intervention was to prevent clawing. The hand was continuously monitored for signs of clawing due to the median and ulnar nerve lacerations.

Also at two and half months post-surgery, radiographs of the distal radius and ulna revealed non-union of the distal radius and ulna; the patient was prescribed a bone stimulator to be worn throughout the day. Treatment at this point had been focused on an aggressive HEP for A/PROM of the digits and wrist all planes. Electrical stimulation (modulation: 10 ms, carrier frequency: 2500 Hz, waveform: 25 continuous biphasic symmetrical sinusoidal cycles, burst duration: 10 ms, burst interval: 10 ms, burst frequency: 50 bups, treatment time: 10 min) was initiated to stimulate the left forearm flexors to improve tendon gliding.

Three months post-surgery, the patient developed adhesive capsulitis of the left shoulder. Passive range of motion to the entire UE was continued, with addition of therapeutic exercises with the pulleys in sitting to improve shoulder flexion and abduction and the upper body ergonometer in sitting to improve shoulder ROM and cardiovascular fitness. Initially, treatment time for each exercise was 3 min. This was progressed to 5 min after the first trial.

To improve dexterity of the hand, neuromuscular re-education was introduced, which consisted of manipulating medium-sized pegs and removing various-sized objects from a gallon-sized bucket, with each exercise performed for a total of 5 min. A pincher grasp was encouraged to remove the plastic medium-sized pegs (diameter of approximately one inch) with each digit and thumb per peg and then replaced to its platform. The bucket was filled with small, white beads which hid various-sized and weighted objects, such as coins, screws, and plastic rings; the patient was encouraged to utilize a pincher grasp to remove the objects, then roll the object between his four digits and thumb. The bucket offered an additional benefit of desensitization of the hand as it was exposed to the various textures within. Conventional ultrasound (frequency: 3.0 MHz, intensity: 1.0 W/cm^2, duty cycle: 100%, coupling agent: gel, treatment time: 8 min) was also initiated and utilized every visit to promote healing and reduce scar tissue formation at the distal dorsal forearm.

At four months post-surgery, therapeutic exercises using pink light resistive Theraband® tubing was initiated to improve left shoulder flexion, extension, internal rotation, external rotation, abduction and adduction for three sets of ten repetitions. At five months, supine wand stretching exercises with a 10 s hold for 10 repetitions were initiated to improve left shoulder flexion and external rotation.

At five and a half months status-post hand replantation, the patient underwent surgical intervention due to left distal radius non-union with left radial wrist stiffness at skin-grafted area despite the electromagnetic stimulation and “good fixation” (see Fig. 2). Surgical intervention consisted of left radius distal third excision of non-union, left iliac crest bone graft harvest and application, extensor carpi radialis brevis and longus tenolysis, and excision of skin graft and closure with transposition of flap.

Second episode of care

Five weeks post-surgery (seven months post-replantation), the patient returned to hand therapy for the second episode of care (EOC2) twice weekly for a duration of four months. The patient initially reported minimal pain in the distal forearm and constant tingling in the fingers and occasional shooting sensation in the palm. He continued to have pain over the iliac crest at the site of the bone graft harvest.

Hand therapy intervention proceeded with AROM, PROM, pain management, edema control, orthotic intervention, and an intense HEP as described in EOC1. Intensive AROM and TGEs were employed to minimize tendon scarring at the wrist and digits. Attention was given to optimizing wrist position for digital motion, specifically 30° wrist extension to maximize digital flexion. An additional desensitization tool was initiated consisting of three textured dowels (cotton, velvet, sandpaper), which were gently rolled over the sensitive skin of the healed incision for 2 min. Caution was utilized with the sandpapered dowel in order to avoid disrupting the integrity of the skin.

Fluidotherapy was initiated at seven months status-post hand replantation prior to hand therapy intervention for 15 min to improve soft tissue mobility and further desensitize the left distal wrist scar. With each fluidotherapy treatment, the hand was carefully inspected at 3–4 min intervals to prevent tissue burn risk. In addition, standing isotonic bicep curls, triceps extension, and overhead press exercises were initiated. All were performed in two sets of 10 repetitions with a resistance of five pounds. A red Therabar® was also introduced to strengthen the left wrist flexors and extensors and was performed for two sets of ten repetitions. The Purdue peg-board was incorporated for neuromuscular re-education for 5 min each session to improve left hand dexterity, pincher grasp, and fine manipulation.

At nine months following hand replantation, the Baltimore Therapeutic Exercise was initiated to improve grip and pinch strength, in addition to wrist flexor, extensor, supination and pronation strength. Each exercise was performed for 60 s, with resistance increased gradually as tolerated. One month later, wrist flexion, extension and radial deviation isotonic exercises were added; wrist flexion was performed utilizing a ten pound weight, while wrist extension and radial deviation were performed utilizing a five pound weight, with each exercise performed for three sets of ten repetitions.

At ten months following hand replantation, the median nerve had not fully recovered, and stiffness in the FDP 2 and 3 as well as scar adhesions over the left dorsal flap persisted. The patient proceeded with surgical intervention of the hand/distal forearm with a pre-operative diagnosis of left hand partial median nerve recovery status post replantation (see Fig. 2). Surgical intervention consisted of palmaris longus to abductor pollicis brevis tendon transfer, carpal tunnel release, median nerve neurolysis, flexor tenolysis of FDP 2 and 3 and FDS 2 and 3, revision of scar and skin closure with advancement of flaps.

Third episode of care

The patient was seen in hand therapy for his third episode of care (EOC3) two and a half weeks post-surgery (~12 months

post-replantation), presenting in a wrist and thumb immobilization orthosis. Initial frequency of therapy was prescribed for twice weekly, however reimbursement issues caused the therapist to reduce frequency to once per week after two weeks, for a total of six visits over four weeks. The patient initially reported a lack of ability to hold his fork, tie his shoelaces, type and grasp with this left hand and severe difficulty buttoning clothing. Hand therapy intervention consisted of STM, A/PROM to the wrist, digits and thumb, TGEs, scar massage, desensitization and sensory re-education, and an intensive HEP. Active attention was given to TGEs, to minimize tendon scarring following the tenolysis procedure, and median nerve gliding exercises to minimize adhesions surrounding the nerve.

Results

First episode of care

At 15 weeks post-surgery, the patient was able to actively flex his long, ring, and small digit to within one half inch of his proximal flexion crease (PFC) and flex his index digit to within one inch of his PFC. Active wrist flexion was 25° and wrist extension was 10° with wrist and digits extended, 15° with digits relaxed. He demonstrated trace muscle activity of the opponens pollicis and abductor pollicis brevis muscle. Gross strength of the shoulder external and internal rotators was 3+/5. The Tinel's test was positive for ulnar, median and radial nerve regeneration at the mid palm.

At 18 weeks post-surgery, the patient presented with a claw hand deformity secondary to decreased ulnar nerve innervations to the intrinsic musculature. At this time, functional limitations consisted of poor opposition of the thumb due to lack of innervations to the thenar muscles, diminished fine motor abilities, and lack of sensibility due to lack of ulnar nerve innervations to the intrinsic musculature.

At 20 weeks post-surgery, it was questionable whether or not the patient had trace strength of the opponens pollicis and abductor digit minimi. The patient demonstrated flexion of all digits to within half an inch of the PFC. He improved functional use of his arm with diminished pain and stiffness of the shoulder. He reported continued tingling in all digits, although aching in his forearm had reduced. EOC1 concluded at 22 weeks with a second surgical intervention to treat non-union of the radius and lack of nerve regeneration of the ulnar and median nerves. Measurements of AROM, strength and sensation prior to EOC1 discharge are listed in Tables 1, 3 and 4 respectively.

Second episode of care

The patient's first visit during EOC2 was five weeks after the second surgical procedures. Upon the first visit, the Patient Specific Functional Scale (PSFS), adapted to upper extremity (UE) function as described by Hefford et al,[5] was administered to determine the patient's functional ability. The patient scored a 12/4 due to an inability to type or eat, moderate difficulty buttoning his pants and mild difficulty washing under the right axilla with his left hand. In the PSFS the denominator represents the total number of functional questions asked, while the numerator represents the 'total score' of the patient's functional ability. Each question is scored 'zero to four' depending on the patient's ability to complete a functional activity; 'four' indicates a complete inability, 'three' indicates severe difficulty, 'two' indicates moderate difficulty, 'one' indicates mild difficulty, and 'zero' indicates no difficulty with the task. Hefford et al[5] demonstrated good responsiveness, construct validity and reliability with assessing UE musculoskeletal injuries with the PSFS.

At the beginning of EOC2, the patient demonstrated little change in AROM measurements for the shoulder, wrist, and digits from EOC1 discharge (see Table 1). Grip strength using a hand dynamometer was tested for the first time (see Table 3), and sensation was formally tested using monofilaments (see Table 4).

Table 3
Muscular strength of left upper extremity

Left UE-strength	EOC1 initial	EOC1 discharge	EOC2 initial	EOC2 discharge	EOC3 initial	EOC3 discharge
Abductor pollicis brevis	0/5	1/5	1/5	1/5	2+/5	3−/5
Opponens pollicis	0/5	1/5	1/5	1/5	2+/5	3−/5
Dorsal interossei	0/5	0/5	0/5	3−/5	3−/5	3/5
Volar interossei	0/5	0/5	0/5	2/5	2+/5	3−/5
Lumbricals	0/5	0/5	0/5	3−/5	3−/5	4−/5
Dynamometer grip strength	NT	NT	27/25 lbs	48/47 lbs	NT	58/57 lbs
Lateral pinch strength	NT	NT	NT	3/4 lbs	NT	6.5/5 lbs
Wrist flexion	NT	3+/5	3+/5	4/5	4/5	4/5
Wrist extension	NT	3+/5	3+/5	4−/5	4−/5	4−/5
Radial deviation	NT	3+/5	3+/5	4−/5	4−/5	4−/5
Ulnar deviation	NT	3+/5	3+/5	4/5	4/5	4/5
Supination/pronation	NT	3+/5	3+/5	4/5	4/5	4/5
Gross shoulder strength	NT	4+/5	4+/5	5/5	5/5	5/5

EOC = episode of care; NT = not tested; Dynamometer values represent two trials.

Thirteen weeks post-surgery, the patient's functional mobility and strength continued to improve. He reported a lack of ability to use a knife and fork with his left hand, but could now tie his shoelaces and grip a golf club, although he tended to lose grip at the end of the swing. He demonstrated minimal clawing in the hand and was able to oppose the thumb to the lateral aspect of the index digit. He appeared to have early return of the median and ulnar nerve, demonstrating notable strength gains in the hand (see Table 3).

Five months post-surgery, the patient reported tremendous improvements in function. The patient reported his only functional limitation was typing secondary to diminished ability to control digits independently. Stereognosis continued to be poor, and there were limitations manipulating objects secondary to intrinsic weakness. The patient did however demonstrate noted improvement in monofilament sensation testing (see Table 4).

Third episode of care

One year following hand replantation, the patient underwent a third surgical procedure, and the patient was seen in hand therapy two weeks post-surgery for EOC3, reporting disappointment with lack of full mobility of his digits. At EOC3 initial assessment, AROM was diminished in the hand and wrist (see Table 1). Upper extremity strength was largely unchanged from EOC2 discharge, with the exception of a noted increase in strength of the abductor pollicis brevis and the opponens pollicis. Sensation was not formally assessed at this time.

Table 4
Sensibility of left hand with Semmes–Weinstein monofilament test (SWMT)

SWMT	EOC1 initial & discharge	EOC2 initial	EOC2 discharge	EOC3 initial	EOC3 discharge
Thumb	NT	No light touch	4.17	NT	4.17
Index	NT	No light touch	4.74	NT	4.03
Long	NT	No light touch	4.74	NT	4.17
Ring	NT	No light touch	4.93	NT	4.03
Small	NT	No light touch	4.74	NT	4.17
Other	NT	Middle palm: 6.65	N/A	N/A	N/A

EOC = episode of care; NT = not tested; N/A = not applicable.

At 30 days post-surgery, the patient reported intermittent pain rated as 2/10, with improved ability to make a fist. At six weeks post-surgery, the patient demonstrated good function with the left palmaris longus transfer. Therapy was terminated prematurely due to reimbursement issues, but at EOC3 discharge, the administered PSFS scored 4/4, with the patient demonstrating no difficulty with buttoning clothes, tying shoe-laces and grasping, mild difficulty holding a fork, and severe difficulty typing. The patient demonstrated prominent gains in hand ROM (Table 1), strength (Table 3), and sensation (Table 4) at EOC3 discharge.

Discussion

Description of a comprehensive rehabilitation associated with the hand following replantation is lacking in the research literature. This case report demonstrated how rehabilitation provided by a CHT was utilized to facilitate functional restoration of the replanted non-dominant hand of a 55 year-old white male. The patient was treated in a hand therapy rehabilitative program for a 13-month duration, during which time he received two additional surgical procedures to address associated complications. Following the rehabilitation and associated surgical procedures, the patient had significant improvement of hand function, strength and sensation, enabling the patient functional use (per patient subjective report) of the replanted hand.

The results from this case report support the moderate amount of information available on the surgical technique of hand replantation, noting that favorable functional outcomes are possible with appropriate surgical and postoperative rehabilitative care, despite a generally decreased return in sensibility and a significant amount of cold intolerance of the hand.[2–4]

Likely factors contributing to the patient's positive outcomes included having immediate access to a specialty hospital for replantation by an orthopedic hand surgeon, advances in modern technology, and a clearer understanding of tissue healing in response to replantation. The combination of these factors indeed has resulted in a reasonably predictable success rate with replantation of an amputated extremity.[3] Success of forearm replantation depends largely on the surgical technique and the type of injury.[6] The most successful recoveries, as was the case with this patient, are amputations occurring with a narrow area of injury and a clean cut. Return of sensation and regaining AROM is much less likely in a limb that has suffered a crush or avulsion injury.[6,7]

According to the literature, positive outcomes of the functional use of a replanted hand, such as with this patient, have been correlated to the reconstruction technique; appropriate debridement and shortening, stable bony fixation, strengthened tendon repair, quality nerve repair, extensive vascular anastomosis, complete skin coverage and early intensive active rehabilitation.[8]

Rehabilitation for this individual consisted of early TGEs and ROM, which according to the literature has also been found to correlate to positive outcomes. Recent studies have indicated that mobilization of repaired tendons can result in a quicker recovery of tensile strength, diminished adhesions, improved tendon mobility, and enhanced tendon healing.[9] Rehabilitation that involves early active mobility offers advantages such as diminished need to protect the repair, promoting simplified post-operative protocols and probably earlier return with functional use of the hand.[9]

A weakness of this case report includes the limited amount of literature available in regards to the outcomes of hand replantation to determine the optimal postoperative management (for flexor tendon repairs).[10] The Kleinert protocol alone often results in diminished digit mobility and increased risk of flexion contractures.[10] Research suggests utilizing early passive protocol such as the modified Kleinert and modified Duran techniques for optimal results.[11] In general, satisfactory functional return is associated with patients <40 years old, proper surgical technique, compliant patients, and patients with primary repairs.[10]

Traumatic hand amputations, such as those cited in previous studies and with this individual, often occur due to a cutting-mechanism such as with a wood-cutting machine, which is high energy trauma often resulting in initial open injury with periosteal stripping.[12,13] While non-union of the distal radius metaphysis are extremely rare, a traumatic amputation of the distal forearm with a wood-cutting saw can often result in a non-union of the distal radius under these circumstances, such as was experienced by this patient at 22 weeks.[13] Fortunately, non-union fractures can usually be treated quite readily with surgical techniques such as the non-vascularized cancellous autograft from the iliac crest and bone-growth stimulators, as this gentleman opted to utilize.[13,14] Literature supports the efficacy of bone-growth stimulators, as they have been utilized over the past 30 years as a critical component of fracture care.[14] Bone stimulators attempt to alter transient electrical properties to promote optimal healing conditions by initiating the inflammatory response until homeostasis is achieved.[14]

An additional treatment modality to promote bone-growth that was utilized for rehabilitation of this patient was low-intensity ultrasound, which has the potential to influence bone growth, signaling and structure.[15] Larsen et al[15] demonstrated in a rabbit model that healing time of fractures could be reduced in the tibial diaphysis and distal radius with pulsed, low-intensity, high-frequency ultrasound treatment administered daily for 20 min sessions. Conversely, the ultrasound regimen did not improve mechanical properties of healing tendons; instead, a slight decrease in stiffness of the tendon was found. A recent systematic review of clinical trials in humans demonstrated that low-intensity pulsed ultrasound therapy facilitated fracture healing, based on radiographic findings, in both fresh fractures and delayed unions or nonunions.[16]

At 18 weeks and 22 weeks post-surgery the patient displayed signs of ulnar nerve and median nerve palsy, respectively, due to the lack of nerve regeneration. While literature relating directly to functional outcomes after a nerve repair status post hand replantation could not be found, limited literature was found on functional outcomes after nerve repair. Nerve repairs are an essential component in determining the functional outcome of a hand replantation. The patient's primary complaints status post rehabilitation were factors related to the lack of nerve regeneration, such as an inability to perceive tactile stimuli, cold intolerance, and weakness with intrinsic muscles of the left hand. Outcomes of a nerve repair are complex in that nerve regeneration depends on a variety of factors, such as the influence of the peripheral and central nervous system.[11] Most changes after a nerve repair occur within the first post-operative year; clinical experience has revealed that the results in adults are often poor, resulting in significant disability. Rosen et al[11] investigated 19 patients status post median or ulnar nerve repair during a four year period to determine their functional outcome. Evaluation methods for the peripheral, sensory and motor function were based on four key components: perception of tactile stimuli motor activity, the absence of pain/discomfort (vital for hand function), and hyperesthesia (cold intolerance in particular). Impairments in any of the four key components can impede one's ability to perform more complex tasks. Their results confirmed that most changes in sensation occurred during the first post-operative year; thereafter, most functional improvements were primarily in motor function.

While rehabilitation of this patient specifically involved sensory re-education, ultimately the outcome for return of sensibility of this individual was poor. As the literature states, a majority of patients

following hand replantation have fairly good motor function return although sensory recovery is poor; additionally, they often suffer from severe cold intolerance.[12] It is unclear as to why these individuals suffer such an extensive loss of functional sensory recovery. One hypothesis could be attributed to substantial neuronal death that happens after nerve injuries, which diminishes the ability of an axon to regenerate and re-innervate the hand. Wiberg et al[12] studied eight subjects utilizing skin biopsies of re-implanted hands to measure the degree of sensory recovery in re-innervated areas, and compared that performance to biopsies obtained from the uninjured hand. Immunostaining techniques demonstrated a 30% loss of sensory fibers and a 60% loss of sympathetic nerve fibers in the re-implanted hand. Additionally, two-point discrimination was only present in those subjects under 40 years of age, noting the more favorable recovery mechanical threshold in younger adult patients. Despite decreased sensibility however, hand function following replantation remains better than that achieved with a prosthesis; sufficient grasp and release is maintained via the extrinsic muscle group, although intrinsic function is often poor, such as was seen with this patient.[17]

After a peripheral nerve injury, extensive cortical reorganization occurs, which has been suggested as the primary reason for poor clinical outcomes after a nerve repair in the hand.[17] Traumatic amputations of the hand often result in large cortical areas of the brain being deafferented, which is followed by extensive cortical reorganization so that the adjacent and contralateral cortical areas take over the function of the vacant area.[17] After a replantation of the hand, functional return can only occur after the peripheral sensory nerves reclaim their original cortical territory.[17] Thus, after hand replantation, studies have utilized functional magnetic resonance imaging to map the activation pattern of the motor cortex; recovery of normal activation pattern varies between patients, but a general consensus of six weeks for normal activation pattern is seen with the majority of hand replantation patients.[17]

The patient in this case also experienced a common complication associated with replantation after a secondary repair; a tremendous amount of scarring of the tendons around repaired nerves and vessels.[18] When the scarring of these structures results in adhesions, tenolysis should be considered.[19] Tenolysis is a well-established surgical procedure intended to restore the gliding of tendons, thus, improving hand function.[19] Successful outcomes are largely dependent upon patient compliance with their rehabilitation program postoperatively.[19] The patient was highly motivated and compliant with all aspects of rehabilitation.

A limitation of this case was a lack of standardized formal functional assessment or performance testing during rehabilitation. While an adaptation of the PSFS as reported by Hefford et al[5] was performed at the beginning of EOC2 and at the conclusion of EOC3, a more comprehensive assessment of the upper extremity, such as the Disabilities of Arm Shoulder and Hand (DASH) questionnaire, would have provided a more specific and objective assessment of the functional gains made by this patient. Additional performance testing would have also allowed for more objective description of the patient's hand function at discharge. The patient did however self-report significant gains in ADL functions of dressing and eating. Additionally, the regular measurement of hand circumference during the rehabilitation process would have allowed for more objective assessment of edema changes.

Conclusion

This case report described the rehabilitation of a 55 year-old male patient who suffered a near complete left distal forearm amputation followed by a hand replantation. Following a protocol focusing on dynamic orthotic intervention, active/passive exercises to improve ROM, grip strengthening, and sensory re-education over the course of a 13-month duration of physical therapy and three episodes of care due to new surgical procedures introduced throughout treatment, the patient demonstrated a significant functional recovery. Upon final discharge, the patient had no difficulty buttoning clothes, tying shoelaces and grasping. He had mild difficulty with holding a fork, and typing was accomplished with severe difficulty despite full active mobility of the digits. The outcome for return of sensibility was poor, as the patient was unable to identify objects by touch without the use of vision and also complained of severe cold intolerance. Successful rehabilitation following hand replantation, as demonstrated in this case, was lengthy requiring not only multiple hand therapy treatment modes and significant patient motivation and compliance, but also supportive surgeries to affect problems of bone non-union, tendon transfer, and excessive scar tissue development affecting neural and muscle tissue.

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