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Outcomes Following Replantation/Revascularization in the Hand

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Synopsis

The variability in reported outcomes and outcome measures used in digit replantation makes it difficult to compare results among studies. This article reviews the principles of measuring functional and patient reported outcomes after replantation, and describes the recommended instruments to use and ways to report results. Outcome values found in the literature are also presented.

Keywords

digit replantation; outcomes after replantation in the hand; functional outcomes; patient reported outcomes; outcome measures

Introduction

Traumatic digit amputation impacts 45,000 people's lives every year.¹ Although usually not life threatening, it decreases the patient's ability to do the same pre-injury tasks and causes psychological stress. Moreover, most patients with traumatic digit amputation are young and of working age. Treatment options include revascularization or replantation of the amputated segment and revision amputation of the stump.

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The most commonly accepted indications for replantation are thumb injuries, multiple digits involved, and injuries in children.^{2,3} For injuries of other digits, there is a perception that replantation is not worthwhile because the functional gain is too small for the cost and efforts required in comparison to revision amputation.^{4,5} However, an increasing number of studies have reported non-inferiority of functional and patient reported outcomes after replantation of single digits.^{1,5–7}

In addition to clinical indications, the decision to replant or not should require a thorough deliberation of the possible surgical outcomes. In other words, patients need a reasonable understanding of the expected level of functional and aesthetic recovery, commitment for rehabilitation, and time required for recovery after replantation before an informed decision is made between replantation and revision amputation.⁸ Those who need to return to work quickly or have limited financial resources may be better served with a revision amputation procedure.⁹

Rigorous evaluation of outcomes after replantation or revascularization is difficult because there are many confounding variables. Moreover, the variability in the types of outcomes reported and the methods used to obtain those outcomes deters a meaningful comparison across studies. Lack of detail for injury characteristics, such as complete versus subtotal amputation, level of injury, and mechanism of injury, and subjective criteria of evaluation further complicate assessment.¹⁰ These challenges in understanding outcomes after replantation need to be considered to establish a standard way to measure and report outcomes to improve the ability to make an evidence-based decision.

In this article, the authors will review the concepts and the recommended ways to measure:

- Initial vascular success
- Functional outcomes
- Patient reported outcomes
- Factors that influence outcomes

Initial Vascular Success of Digit Replantation

In the immediate postoperative period, close monitoring of vascular patency is key to the survival of the replanted digit.⁸ Perfusion should be monitored by examining the color, pulp turgor, capillary refill, and temperature of the replanted digit.¹¹ A soft, pale fingertip with delayed capillary refill of more than 2 seconds indicates arterial occlusion, and an edematous, blue fingertip with rapid capillary refill indicates venous occlusion. Lower temperature in the replanted digit greater than 2°C is a discouraging sign for digit viability. To improve perfusion, constrictive sutures and dressings should be taken down first (Figure 1). Leeches and heparin-soaked pledgets can be attempted to allow for egress of blood from the digit. Lastly, the patient can be taken back to the operating room for exploration of the vascular anastomoses. The expected survival rate for digital replantation and revascularization is 50–85%.¹¹

In the literature, the reported rates of initial vascular success vary widely, depending on the follow up period, types of digits evaluated, and the characteristics of the injury. In fact, the definition of successful replantation differs between different study designs. Owing to the limits of coding scheme and data structure, the rates of successful replantation reported by many database studies are actually rates of initial vascular survival of the replanted digit. For instance, a national-level investigation using the largest inpatient database from 1998 to 2012 found a 79% rate of success for thumb and 67% for other digits, but was unable to perform subgroup analyses by individual digit type or mechanism of injury because of the lack of information in the database.¹² In addition, it is unclear whether this data captures late revision amputations. Similarly, another retrospective database study found a 70% rate of survival from 2008 to 2012 but did not provide rates for subcategories of digit types or injury types.¹³

On the other hand, studies based on clinical data can report detailed results. For example, in a study of 121 digit replantations over a 14-year period between 1997 and 2010 at large academic level I trauma centers, Fufa et al. defined survival as digit viability for a minimum of 21 days, and found a 57% rate of survival. They found higher survival rates for the thumb (68%), index (63%), and long (65%) fingers compared to the ring (35%) or small (36%) fingers. Regarding the mechanism of injury, sharp injuries (55%) had a similar rate of survival as avulsion injuries (56%), which were unexpectedly lower than the survival rate for crush injuries (68%).¹⁴ When classified by level of amputation, Tamai level V (most proximal) showed the highest rate of survival at 80%, followed by level II (67%), level IV (55%), and level III (53%) (Table 1).^{14,15} Replantation in non-smoking patients showed a higher rate of survival (65%) than those who smoked (45%). Replantation procedures that included multiple venous repairs showed higher rates (64%) than those with 0 or 1 venous repair (46%). As surgeon years in practice increased, the rates of survival increased as well. Replantation cases performed by surgeons with less than 5 years of experience had a 49% rate of survival, whereas 68% of the cases survived when performed by those with more than 10 years of experience.¹⁴

Clinical studies can provide detailed information that may help with surgical decision making, but there are many factors that influence the surgical outcome, such as patients' comorbidities, smoking status, and injury severity.² The results of one clinical study may not be generalizable, that is the findings are not relevant to patients at another hospital for various reasons. For instance, patients' characteristics, the level of expertise of surgeons, the operative staff, and inpatient care resources may differ from one institution to another.

A systematic review compiles and tabulates data from multiple studies to diminish selection bias, and thus may be more appropriate for evidence-based clinical decision-making. A meta-analysis of 8 clinical studies compiled data from 1,803 digit replantations in 1,299 patients, to examine how different factors affect survival rates (Table 2).¹⁶ Rates of survival were similar for injury levels from distal interphalangeal joint to proximal phalanx (88–89%) but were lower for distal phalanx (78%) and metacarpophalangeal joint (79%). Middle (83%), ring (83%), and little fingers (89%) had higher survival rates than thumb (68%) or index finger (75%). Clean injuries survived at a higher rate (91%) than crush (68%) or avulsion injuries (66%). A systematic review solely assessing digit replantation after

avulsion injuries found 68% rate of survival for thumb avulsion injuries and 78% for finger avulsion injuries.¹⁷ Another systematic review of 2,273 distal digit replantations found the overall survival rate to be 86%, with no difference between Tamai level I and II amputations.⁶ Clean cut injuries survived at a much higher rate (92%) than crush (80%) or avulsion type injuries (75%) (Figure 2), and those with vein repair showed higher survival rates for both Tamai level I (92% versus 83%) and level II (88% versus 78%) amputations.⁶

The rates of digit survival found in the literature vary greatly, but a meaningful comparison is difficult as database studies lack details on injury characteristics and results from single institution are not generalizable. We recommend that the survival of the replanted digit be assessed at least 21 days after the operation to ensure definitive viability, and specific injury characteristics be reported to generate high quality evidence.

Functional Outcomes after Replantation

Although many studies discuss successful replantation, the term should be reserved for cases that demonstrate satisfactory functional outcomes and not merely digit survival.² Success should convey a meaningful contribution of the replanted digit to the patient's level of functional capacity, measured at least one year after the surgery to account for any secondary procedures and further improvement in function.¹⁰ In other words, replantation cannot be deemed successful until adequate function is restored.¹¹ The traditional measures of functional outcome measurement after digit replantation include range of motion, sensation, and grip/pinch strength.

The scoring system constructed by Tamai is designed to evaluate functional outcomes as well as patient-reported outcomes after digit replantation, by including categories such as activities of daily living, patient satisfaction, and subjective symptoms (Table 3).¹⁵ Each outcome category is evaluated for a numerical score, and the total score ranges between -10 and 140. Although this scoring system provides an objective measurement, the scoring process is highly subjective, with criteria such as mild, moderate, and severe, without any specific definitions. Another scoring system, Chen's criteria, quantitatively evaluates 4 outcome parameters (return to work, range of motion, sensory and motor recovery) for a grade I through IV, but still calls for a subjective assessment without a specified standard method of measuring outcomes (Table 4).¹⁰ One study compared the two scoring tools by applying them to evaluate functional outcomes after transmetacarpal replantation, and concluded that Tamai's scores represent realistic function of the hand despite being more complicated to use.¹⁸

In this section, we will review the recommended parameters for an objective, quantifiable outcomes evaluation.

Arc of Motion

We recommend that the range of motion be reported by measuring total active motion in degrees, because it takes into consideration any joints that were fused, range of motion of remaining joints, and flexor and extensor functions. Total active motion (TAM), as described by the American Society for Surgery of the Hand, is the sum of active range of motion

measured with a goniometer in the metacarpophalangeal (MCP) joint, proximal interphalangeal (PIP) joint, and distal interphalangeal (DIP) joint for each individual digit (Figure 3). Normal active range of motion is 80° at DIP joints of finger and IP joint of the thumb, 100° at PIP joints, 90° at finger MCP joints, and 55° at thumb MCP joints. Normal TAM is 135° for the thumb and 270° for fingers.^{19,20} For amputation injuries in flexor zone I, or distal to the insertion point of flexor digitorum superficialis (FDS), the expected arc of motion is greater than the injuries more proximal because the FDS tendon is intact and uninjured.^{2,21,22} Similarly, ring avulsion injuries with damage to skin and the vasculature only show good motor recovery if the FDS is intact.² In the literature, the reported values of TAM depends on the level of injury and the digit injured (Table 5 and table 6).^{5,17,18,23–28} The mean TAM appears to decrease as the injuries are more proximal (Figure 4).

Sensation

We recommend assessment of sensory recovery of the replanted digit using a two-point discrimination (2PD) test or by Semmes-Weinstein Monofilament (SWF) testing. 2PD test is the most commonly used tool to measure sensory outcome after nerve repair.²⁹ It examines tactile gnosis, the replanted segment's sensory function to discern that two nearby objects in contact with the skin are two distinct points of touch. The standard way of assessment is for the examiner to find the shortest distance between two points of touch using calipers, by starting wider than the expected value and moving the two points closer and closer.³⁰ The normal values in the hand are: thumb (2.5–5mm), index (3–5mm), other digits (4–6mm), palm (11mm), dorsal metacarpal (7–12mm).²⁹ SWF is a commonly used tool to detect peripheral neuropathy for the loss of protective sensation.³¹ The monofilaments are applied to skin perpendicularly until the fiber bends slightly, for approximately 1.5 seconds. The patients report whether they can feel the monofilament or not.³² There are various monofilament sizes (1.65 to 6.65) with different amounts of target force calibrated. The clinician records the smallest monofilament size that the patient is able to detect.

Among studies that reported sensory recovery outcome measured by 2PD test, some reported the actual distance measured and others the percentage of cases that fell into distance groups. Boeckx et al. reported that 59% of 34 single digit replantations were categorized to have 2PD of >15mm, and 34% show a fair to bad recovery of sensory function (6–15mm). Only 3% showed normal sensibility of <6mm.²³ In another study of single digit replantation cases, Chen et al. also categorized their results in groups: 17% of cases were in <6mm category, 47% in 6–10mm category, 17% in 11–15mm category, and 20% in >15mm category.²⁶ The actual distances reported by other studies is presented in Table 7 and table 8.^{6,17,18,23–26,28,33–35}

There were 2 studies that reported sensibility testing using SWF. Paavilainen et al. found 55% of transmetacarpal replantation cases to fall within the normal range (2.83 – 3.61), with diminished protective sensation (4.31) in 22%, loss of protective sensation (4.56) in 14% and loss of sensation in 9%.¹⁸ Instead of reporting the monofilament size, Chen et al. reported the target force applied by the different-sized monofilaments. They reported a normal sensation of touch (0.07g) for 27% of digit replantation cases, 0.4g in 33%, 2g in 30%, 4g in 3%, and loss of sensation (300g) in 7%.²⁶

Grip Strength

We recommend that grip strength be measured with a Jamar hydraulic hand dynamometer, because it is a reliable and validated instrument.^{10,36} The Jamar dynamometer has adjustable handles with 5 different positions, with different distances between the instrument body to the handle. Different handle positions influence the measured grip strength. We recommend handle position 2 (4.8cm distance), as it was shown to produce maximal grip strength in the participants.^{36,37} Patients should sit in a straight-backed chair, feet flat on the ground, shoulder adducted, elbow flexed at 90°, and forearm and wrist in neutral position (Figure 5).^{37,38} Dynamometers measure strength in weight (kilograms or pounds). We recommend reporting the ratio of measurements, between the affected side and normal side.¹⁰ Reporting ratios takes into consideration the individual variability of strengths among patients, because what is normal for one patient may be considered as decreased power for another patient.

For an overall assessment among digit replantation cases, (non-specific of digit injured or level of injury), the mean grip strength reported were 20kg³⁵ and 39.6kg (91% of normal side).²⁶ Rosberg et al. analyzed 326 digit replantations and reported grip strength as a ratio to the normal side, by digit type and level of injury: thumb 84%, fingers 64%, mid-hand 56%, wrist 28%, and proximal to wrist 26%.³⁹ For fingertip replantation, Hattori et al. found 83% grip strength in their review of 23 cases.⁷ For transmetacarpal replantation, the mean grip strength measured was 56% among 33 cases.¹⁸ For more proximal injuries, the mean grip strength was 39% of normal.²⁵

Return to Work

Patients may have an easier time returning to jobs that require less manual and digit function. To control for this variability, we recommend assessing this parameter by categorizing whether the patient was able to return to the same job, had to get a different job, or was not able to work at all.¹⁰

There were several studies that used scoring systems by Tamai and Chen to evaluate the functional outcomes after replantation, but none of them reported specific results for each variable within the scoring systems.^{18,25,35} A systematic review of distal digit replantation by Sebastin et al. evaluated 30 studies for working status, but did not mention whether the patients had returned to their original work or not.⁶ We found three studies specifically mentioned the job status of the patients.^{23,25,33} The study by Assouline et al. reported Chen's grade for each patient but mentioned the job status for only 5 of their 11 cases; 3 patients returned to their original job and 2 patients were classified as disabled. Boeckx et al. reported that 8 out of 13 patients returned to same job, 2 changed jobs and 2 did not return to work. Wu et al. found that all of the 33 patients who worked before their injuries returned to their original workplace.

Complications

There are numerous potential complications after replantation with a variety of different ways to measure them. Thus, it is difficult to compare results between studies. Categories such as severe, moderate, and mild rely on subjective assessment of the evaluator, and this introduces a great deal of bias. Therefore, we recommend reporting complications as present

or absent. Among the possible complications such as pain, tightness, color change, and scarring, we recommend reporting on cold intolerance, pulp atrophy, and nail deformity as a minimum set.¹⁰

In the literature, we found that studies varied greatly in their report of both the type of complications assessed and the method used to evaluate them. Hahn et al. reported that out of 468 successful digit replantations, 117 fingers had nail deformity (25%), 46 developed a nonunion (10%), 47 had pulp atrophy (10%), 41 had paresthesia (8%), and 14 patients had intractable pain (3%).³⁴ Chen et al. applied the Cold Intolerance Severity Scoring Scale (0–100) to measure the severity of cold intolerance, and found a mean score of 31 among 30 cases of single digit replantations.²⁶ Wu et al. used their own scoring system and found that among 35 patients, 25 patients reported no cold intolerance, 5 with mild intolerance, 3 with moderate, and 1 with severe symptoms.³³ In a systematic review of distal digit replantation (flexor zone 1) studies, Sebastin et al. found 87 cases reporting pulp atrophy and 156 cases of nail deformity among 683 cases with long-term follow-up.⁶ Hattori et al. assessed for presence of pain (2), paresthesia (7), and cold intolerance (8) for 23 successful replantation cases of injury at Tamai zones I or II.⁷ For transmetacarpal replantation, 100% of patients with some recovery of sensibility reported experiencing cold intolerance, but 50% reported diminishing symptoms within 5 years.¹⁸

Patient Reported Outcomes after Replantation

Patient reported outcome measures provide an insight to patients' experience and their subjective evaluation of the care received. It is especially important for interventions such as digit replantation that takes the wish of patient into consideration for surgical decision making.⁴⁰ By evaluating a patient's experience, providers can assess the benefits of treatment from the perspective of the very recipients of the treatment.⁴¹ Important data such as the ability to perform activities of daily living, quality of life, and satisfaction can only be obtained from the patient.⁴² Assessment of patient reported outcomes is essential for a complete evaluation of the efficacy of digit replantation.

There are numerous questionnaires to measure patient reported outcomes in health care, with varying levels of appropriateness for different diseases and interventions. For instance, there are over 15 different types of health-related quality of life scales that can be used in hand surgery.¹⁰ Among many, the Michigan Hand Outcomes Questionnaire (MHQ)⁴³ and the Disabilities of the Arm and Shoulder (DASH) Questionnaire⁴⁴ have been found to be valid and reliable in the assessment of patient reported outcomes related to care received for hand trauma.⁴⁵ For a robust collection and comprehensive analysis of data, these questionnaires should be administered at multiple time points during the treatment process.

The MHQ

The MHQ is a 37-item questionnaire with individual scales for overall hand function, activities of daily living, work performance, pain, aesthetics, and satisfaction with hand function. In each scale, higher scores denote better hand performance, with the exception of the pain scale that equates high scores with greater pain. The raw scale score for each of the 6 scales is the sum of responses normalized by numerical normalizing algorithms. The raw

score can be converted to a score ranging between 0 and 100. Each hand is assessed separately. If both hands are affected, the right hand scores and left hand scores can be averaged.⁴³

Zhu et al. assessed patient reported outcomes via the MHQ for single digit replantation by digit type and level of injury (Table 9).²⁷ They found higher scores for more distal level of injury for each digit. They also compared the MHQ scores of each subgroup to the amputation cases that underwent revision amputation, and found superior results for thumb and index finger at all levels of injury, and at more proximal levels for middle (level II – V) and ring (level IV and V) finger replantation. Similar results were seen in the study by Kamarul et al., with mean MHQ scores for digit level injuries (thumb 67.6 and fingers 72.0) being higher than proximal injuries at the palm (50.0) or the wrist (52.8).⁴⁶

The DASH

The DASH questionnaire consists of 30 questions that assess the symptoms and functional status of patients with upper extremity diseases or injuries, on a 5-point Likert scale. The components included for symptoms are pain, weakness, stiffness, and paresthesia. Physical performance evaluations are based on the patient's ability to perform daily activities, house/yard chores, shopping/errands, recreational activities, self-care, dressing, eating, sleep, and sports/performing arts. For social functional status evaluation, the questions address family care, occupation, and socializing with friends/relatives. Psychological well-being is assessed by self-image. There are assigned values for each of the possible responses, and they can be summed and converted to a score between 0 and 100, with higher scores indicating more severe disability.⁴⁷

A review of 30 single digit replantation cases by Chen et al. found the mean DASH score to be 6.6, indicating good hand functionality.²⁶ In another study, Tessler et al. found superior scores for replantation (24.0) versus revision amputation (21.9). Within the replantation group, dominant side replantation (29.7) was found to result in greater disability compared to the non-dominant side replantation (18.0).⁴⁸ For more distal level replantation, Hattori et al. found a mean DASH score of 2 for 23 successful fingertip replantation cases. This result echoes the findings by the studies that used the MHQ, that distal digit replantations show greater functional recovery than those more proximal. In comparison with the scores from the revision amputation group (mean DASH score 7), the successful replantation was correlated with better functional status.⁷

Some studies used the Quick DASH questionnaire, an abbreviated version of the DASH with adequate validity and reliability. The Quick DASH also generates a score between 0 and 100, with 100 indicating greater disability.⁴⁷ Rosberg used this tool to evaluate 326 replantation cases, and found a mean score of 11.4. In subgroup analyses, higher Quick DASH scores were found for more proximal levels (Wrist 43.2, Proximal to Wrist 29.5) compared to middle hand level (13.6). There was no difference in Quick DASH scores for thumb (9.1) and finger (9.1) replantations.³⁹ Kamarul et al. showed lower Quick DASH scores for finger (26.3) than thumb (30.1), but the digit level replantations were associated with better functional status than more proximal level replantations (Palm 60.2, Wrist 56.3).⁴⁶

Factors Influencing Outcomes after Replantation

There are multiple factors that influence the outcome of replantation surgery in the hand. Patient factors such as age,⁴ comorbidities, especially those that compromise peripheral perfusion such as diabetes, autoimmune diseases, and collagen vascular diseases,^{2,49} have been reported to influence outcomes. Hustedt et al. found that patients with more than three comorbidities had a significantly higher rate of failed replantation, and greater relative risk of failure among patients with peripheral vascular diseases.⁵⁰ Multiple studies found significant difference in rate of replant survival for patients who smoked and those who did not,^{49,51} with 3 times higher odds of successful replantation for non-smokers.¹⁴

Level of injury and the mechanism of injury have also been mentioned by multiple expert hand surgeons to influence outcomes after replantation.^{2,4,8,15} In fact, the characteristics of the amputation heavily influence the level of clinical indication for replantation.^{4,8} Soucacos stated that functional outcomes after replantation for injury in flexor zone 1 and 3 tend to be better than those in zone 2, because of intact FDS in zone 1 and better vascular supply by superficial or deep palmar arch in zone 3 compared to common digital arteries in zone 2 (Figure 6).² Multiple studies have found superior outcomes for arc of motion, grip strength, and subjective functional recovery for distal digit replantation compared to more proximal injuries.^{5,7,17,23,24,27,39} Clean-cut, or guillotine amputations, have been noted to produce better outcomes.^{2-4,15,51}

Many experts have stated that ischemia time heavily influences the survival of replant and the long term functional outcomes.^{2,3,46,51} In digit replantation consideration, Soucacos suggested a maximum of 8 hours for warm ischemia and 30 hours for cold ischemia. However, with advances in microsurgery, more recent studies have published non-inferior outcomes for cases with prolonged ischemia times.²² Rather than conducting the replantation procedure during the night when the surgeon is tired or the team assembled is not familiar with the instrumentation, delayed elective replantation in working hours provides the most optimal condition for performing this tedious and intricate procedure. Woo et al. have found that total survival rate in delayed replantation (88%) was not statistically different from the survival rate in immediate replantation (84%). Furthermore, they evaluated the delayed replantation cases by Chen's criteria and found good (grade II) and excellent (grade I) functional recovery.³⁵ Cavadas et al. analyzed 597 digit replantation cases and found similar survival rates between the immediate replantation group (91%) and delayed replantation group (93%).⁵²

Factors on the provider side, such as surgeon skill and experience, and facility's level of excellence have been noted to influence outcomes after replantation.^{2,4,7,8} Surgeons with more than 10 years of experience had higher rate of survival (68%) in digit replantation compared to surgeons with 5–9 years of experience (57%) and less than 5 years of experience (49%).¹⁴ Related to surgical expertise, Hahn et al. found that higher number of vascular anastomoses completed during replantation correlated with higher rates of survival. They reported a 68% rate of survival for 1 arterial anastomosis group, 82% for 1 arterial and 1 venous anastomoses group, 95% for 1 arterial and 2 venous anastomoses group, and 99% for 2 or more arterial and 2 venous anastomoses group.³⁴

Hospitals with high case volume have demonstrated higher rates of replant survival, along with higher odds of success.^{12,13,53,54} For thumb replantation, hospitals with 20 cases or more showed 2 times higher odds of success.⁵³ Moreover, digit replantation performed by high-volume surgeons (>5 cases per year) at high-volume hospitals (>20 cases per year) had 2.5 times greater likelihood of survival.¹² Brown et al. showed that a minimum of 3 cases per year was required for a hospital to achieve a 70% rate of success with digit replantation.¹³ Efforts towards regionalization for replantation in the hand will likely improve outcomes.

A patient's level of commitment and adherence to rehabilitation protocols can directly influence the outcomes of replantation. In addition, it appears that validated outcomes are strongly influenced by depression and anxiety.^{55,56} Depression is correlated with the severity of trauma perception after replantation.⁵⁷ A recent study by Efanov et al. showed that use of patient-advisors in the rehabilitation period helped improve functional recovery and quality of life, as the group of patients with patient-advisors showed superior DASH scores (29.6 versus 34.8).⁵⁸

Conclusion

Functional outcomes and patient reported outcomes together assess the benefits of replantation for amputation injuries in the hand. However, the current literature does not provide high quality evidence, owing to the variability in the outcomes reported, instruments used to measure, and means of reporting data. In addition, many studies do not include details of the confounding factors that influence outcomes. Establishing a standard for outcomes evaluation and reporting will help patients and surgeons make informed treatment decisions based on evidence.

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Key Points

- There is a great deal of heterogeneity in the literature for measurement tools and reported outcomes for replantation in the hand.
- Both functional outcomes and patient reported outcomes together facilitate a comprehensive assessment of the benefits of replantation for amputation injuries in the hand.
- Recommended parameters to measure are: digit survival, arc of motion, sensation, grip strength, return to work, complications, and patients' perspectives on overall hand function, activities of daily living, pain, work performance, aesthetics, and satisfaction.
- Factors influencing outcomes include patient age, comorbidities, specific digit(s) injured, level of injury, mechanism of injury, surgeon skill and experience, and hospital volume.
- Establishing a recommended set of outcomes, outcome measures, and ways to report them will improve the quality of evidence that permits patients to make informed decisions.

Figure 1.
Release of Constrictive Sutures to Improve Perfusion.

Figure 2.
Crush Injury by Industrial Pressing Machine.

Figure 3. Measuring (A) flexion and (B) extension with a goniometer.

From Wiig ME, Dahlin LB, Fridén J, et al. PXL01 in Sodium Hyaluronate for Improvement of Hand Recovery after Flexor Tendon Repair Surgery: Randomized Controlled Trial. PLoS ONE 2014; 9(10): e110735; with permission.

Figure 4.
Decreased Range of Motion after Replantation at Proximal Level of Injury.

Figure 5. Measuring Grip Strength with a Jamar Dynamometer. (A) Instrument at Position 2. (B) Standard Patient Position.

From Han SH, Nam KS, Cho YS, et al. Normative Data on Hand Grip Strength. J Nov Physiother 2011; 1:102; and Sammons Preston, Bolingbrook, IL.

Figure 6.
Zone 2 Injury.

Table 1.

Tamai Classification of Digit Amputation Level

Level	Description
I	Distal to flexor digitorum profundus insertion
II	Distal interphalangeal joint to flexor digitorum profundus insertion
III	Middle phalanx distal to flexor digitorum superficialis insertion
IV	Proximal phalanx to middle phalanx flexor digitorum superficialis insertion
V	Metacarpophalangeal joint and proximal

Adapted from Sebastin SJ, Chung KC. Challenges in measuring outcomes following digital replantation. *Semin Plast Surg* 2013;27(4):174–181; with permission.

Table 2.

Rates of Survival by Injury Characteristics

Injury Characteristics	Subcategory	Rate of Survival
Mechanism of Injury	Clean	91.4%
	Crush	68.4%
	Avulsion	66.3%
Zone of injury	Distal phalanx	77.7%
	Distal Interphalangeal joint	88.9%
	Middle phalanx	87.7%
	Proximal Interphalangeal joint	88.7%
	Proximal phalanx	88.9%
	Metacarpophalangeal joint	78.9%
Digit injured	Thumb	68.1%
	Index	75.0%
	Middle	82.8%
	Ring	82.8%
	Little	88.9%

From Dec W. A meta-analysis of success rates for digit replantation. Tech Hand Up Extrem Surg 2006;10(3):124–129; with permission.

Table 3.**Tamai Scoring System**

Range of Motion (0–40)		
Thumb	Opposition: Possible (10), Difficult (5), Impossible (0)	
	Total Range of Motion: >50% of normal (10), <50% of normal (5), Stiff (0)	
Fingers	Total Range of Motion: >151° (20), 111–150° (15), 71–110°(10), <70°(5), Stiff (0)	
Activities of Daily Living (0–20)		
Pushing, Tapping, Hanging or drawing, Grasping soft material, Grasping hard material, Power grasp, Picking up a coin, Picking up a needle, Wringing a towel, Dipping up water, Washing face, Knotting, Buttoning, Writing, Scissoring, Hammering, Using screw driver, Using clothes pin, Fumbling in pocket, Showing rock, paper, scissors		For each category, Easy (1), Difficult (0.5), Impossible (0)
Sensation (Grading by British Medical Research Council) (0–20)		
No recovery of sensibility (S0) (0)	Recovery of superficial pain sensibility (S1) (4)	Recovery of superficial pain and some touch sensibility (S2) (8)
Recovery of pain and touch sensibility with disappearance of overresponse (S3) (12)	S3 level of recovery but localization of stimulus is good with imperfect recovery of 2-point discrimination (S3+) (16)	Complete Recovery (S4) (20)
Subjective Symptoms (0–20)		
Pain, Cold intolerance, Numbness, Paresthesia, Tightness, etc		Severe (–3), Moderate (–2), Mild (–1)
Cosmesis (0–20)		
Atrophy, Scar, Color change, Deformities (angulation, rotation, mallet, swan neck, buttonhole, etc)		Severe (–3), Moderate (–2), Mild (–1)
Patient Satisfaction (0–20)		
Highly satisfied (20), Fairly satisfied (15), Satisfied (10), Poorly satisfied (5), Not satisfied (0)		
Job Status (–10–0)		
Same job (0), Changed (–5), Cannot Work (–10)		

Adapted from Sebastin SJ, Chung KC. Challenges in measuring outcomes following digital replantation. *Semin Plast Surg* 2013;27(4):176; with permission.

Table 4.

Chen's Criteria

Grade	Return to Work	Range of Motion	Sensory Recovery	Motor Recovery
I (Excellent)	Resume original job	>60% of normal	Normal	4–5 out of 5
II (Good)	Resume suitable work	>40% of normal	Near normal	3–4 out of 5
III (Fair)	Independent activities of daily life	>30% of normal	Partial recovery	3 out of 5
IV (Poor)	No recovery of useful function			

Adapted from Sebastin SJ, Chung KC. Challenges in measuring outcomes following digital replantation. *Semin Plast Surg* 2013;27(4):176; with permission.

Table 5.

Total Arc of Motion (°), by Level of Injury

Authors	Flexor I	Middle Phalanx	PIP Joint	Proximal Phalanx	Flexor II	Metacarpus	Metacarpus to Distal Forearm
Boeckx et al. ²³	-	151	106	95	-	109	-
Buntic et al. ⁵	170	-	-	-	133	-	-
Adani et al. ²⁴	180	-	-	-	-	-	-
Paavilainen et al. ¹⁸	-	-	-	-	-	154	-
Assouline et al. ²⁵	-	-	-	-	-	-	203

Table 6.

Total Arc of Motion (°), by Digit Type

Authors	Overall	Thumb	Fingers	Index	Middle	Ring	Small
Chen et al. ²⁶	-	75	145	-	-	-	-
Zhu et al. ²⁷	-	136	192	-	-	-	-
Boeckx et al. ²³	112	-	-	104	105	131	145
Adani et al. ²⁴ ‡	-	-	-	-	-	185	-
Sears et al. ¹⁷ ‡	-	-	-	-	-	174	-
Bamba et al. ²⁸ ‡§	-	-	-	-	-	179	-

‡These studies only studied ring avulsion injuries.

§Subgroup analysis showed mean TAM of 201° for Urbaniak class I (circulation adequate) injuries, 187° for class II (circulation inadequate), and 168° for class III (complete degloving or complete amputation).

Table 7.

Two Point Discrimination Test Results (mm), by Level of Injury

Authors	Tamai I	Distal Phalanx	Middle Phalanx	PIP Joint	Proximal Phalanx	Metacarpus	Metacarpus to Distal Forearm
Boeckx et al. ²³	-	-	15.9	24.9	17.5	18.5	-
Wu et al. ³³	7.7	-	-	-	-	-	-
Hahn et al. ³⁴	7	-	-	-	-	-	-
Sebastin et al. ⁶	-	-	-	-	-	-	-
Paavilainen et al. ¹⁸	-	-	-	-	-	14.7	-
Assouline et al. ²⁵	-	-	-	-	-	-	14.1

Table 8.

Two Point Discrimination Test Results (mm), by Digit Type

Authors	Overall	Ring Finger
Woo et al. ³⁵	11.7	-
Chen et al. ²⁶	10.4	-
Adani et al. ²⁴ †	-	185
Sears et al. ¹⁷ †	-	174
Bamba et al. ²⁸ †§	-	179

†These studies only studied ring avulsion injuries.

§Subgroup analysis showed mean 2PD of 5.6mm for Urbaniak class I (circulation adequate) injuries, 8.3mm for class II (circulation inadequate), and 10.5mm for class III (complete degloving or complete amputation).

Table 9.

Patient Reported Outcomes by Injured Digit and Level of Injury

Tamai Level*	Thumb		Index		Middle		Ring		Small	
	Cases (N)	MHQ Score	Cases (N)	MHQ Score	Cases (N)	MHQ Score	Cases (N)	MHQ Score	Cases (N)	MHQ Score
I	11	91.3 ± 5.6	5	95.4 ± 4.1	6	94.5 ± 4.7	5	96.5 ± 6.1	4	95.6 ± 4.9
II	27	92.1 ± 6.8	8	96.1 ± 3.7	7	95.1 ± 4.8	12	95.7 ± 6.2	10	95.2 ± 7.9
III	41	88.9 ± 8.2	11	88.2 ± 9.6	9	88.5 ± 11.2	10	87.2 ± 6.8	11	91.3 ± 6.8
IV	0	-	15	85.4 ± 12.9	14	84.3 ± 9.9	11	84.1 ± 13.5	12	91.3 ± 7.8
V	33	83.0 ± 10.5	11	83.5 ± 12.1	8	84.1 ± 7.6	6	82.9 ± 4.7	23	88.6 ± 11.5

*For description of each Tamai level, please refer to Table 1. Higher MHQ scores indicate better hand function.

From Zhu H, Bao B, Zheng X. A Comparison of Functional Outcomes and Therapeutic Costs: Single-Digit Replantation versus Revision Amputation. *Plast Reconstr Surg* 2018;141(2):244e-249e; with permission.