Reviews

Replantation/revascularization of single finger flexor Zone II injuries: a controversial issue, especially in the index finger

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Abstract

Amputations through flexor Zone II in single fingers, especially the index, historically have had poor functional outcomes. Due to this, summary evidence often lists replantation of these injuries as a relative or an absolute contraindication. This manuscript re-evaluates these recommendations in view of current evidence.

Current survival rates for replantation of flexor Zone II injuries vary based on mechanism with sharp mechanisms having greater survival than crush and avulsion injuries. The impact of smoking on replant survival has mixed evidence with recent evidence suggesting a dose-response relationship. Active range of motion outcomes have not improved significantly since the oft-quoted Urbaniak and Ross studies with average active range of motion ranging from 109º - 155º varying by mechanism of injury and repair type. Index injuries impose less quadriga effect on neighboring digits. Sensation outcomes are particularly important for index replantation with functional bypass occurring below a yet to be established threshold. Workers' compensation involvement is a significant risk factor for poor patient reported outcomes. Subjective measures, such as the DASH score, varies with time since injury, traumatic vs therapeutic amputation, and correlates poorly with objective outcomes. Worker's compensation cases, cases that involve litigation, and patients employed in manual labor vocations experienced slower return to work following replantation. Secondary ray amputations experienced poorer subjective outcomes and delayed return to work.

The purpose of this paper will help medical students establish a clear understanding of the relevant measures of hand function and to be aware of the current literature informing clinical decision-making regarding replantation of digits amputated through flexor Zone II.

Introduction

Background

Injuries to the fingers are the third most common workplace injury in Canada.[1] These statistics do not consider digit injuries sustained outside of work and therefore underestimate the total healthcare burden attributable to these injuries, with 25% of digit amputations occurring at home.[2]

The key decision in any digit amputation is whether to attempt replantation or to proceed with revision amputation. In many cases, this is a difficult decision for both the patient and the surgeon. Both must consider the feasibility of replantation, functional outcomes specific to the biomechanics of the injured finger, and the implications for the patient's daily activities and job. The ideal outcome for replantation is restoration of a stable, pain-free, sensate digit with acceptable range of motion (ROM). While these goals are not always met by replantation, they are obviously never met by amputation. Historically, replantation of the index finger has had poor functional outcomes in adults.[3-5] Due to this, single index finger replantation has remained controversial and is often listed as a relative contraindication or a hinderance to hand function if replanted.[4,6-8]

Review Methodology

This paper is a non-systematic summary review. The primary author collected the current summary evidence relevant to the topic from Green's Operative Hand Surgery, Plastic Surgery Volume 6: Hand and Upper Extremity and Grabb and Smith's Plastic Surgery. The primary evidence referenced for the summary recommendations was then compiled and reviewed. The University of Calgary library collections database was then searched using combinations of relevant outcome measures (survival, ROM, sensory return), anatomical zones of interest (index, flexor Zone II) in the topic of interest (finger replants/revascularizations). After review by the other authors, patient-reported and return to work (RTW) outcomes were added to the search terms. All article titles and abstracts were reviewed and selected at the discretion of the primary author based on perceived relevance to the outcome measures idenified in the summary evidence. As such, the included articles may reflect the bias.

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Definition of Terms

Metacarpal (MC) – Long bone of the hand articulating with the carpal bones proximally and phalanxes distally. Numbered 1 through 5 from radial to ulnar aspect, i.e. thumb MC and small MC are MC #1 and MC #5, respectively.

Metacarpophalangeal joint (MCPJ) – Condyloid articulation between the metacarpal and proximal phalanx.

Proximal Phalanx (PP) – Proximal long bone of the finger articulating with the metacarpal proximally and middle phalanx distally.

Proximal Interphalangeal Joint (PIPJ) – Hinge articulation between the proximal phalanx and middle phalanx

Middle Phalanx (MP) – Intermediate long bone of finger articulating with the proximal phalanx proximally and distal phalanx distally.

Distal Interphalangeal Joint (DIPJ) – Hinge articulation between middle phalanx and distal phalanx

Distal Phalanx (DP) – Distal long bone of the finger articulating with the middle phalanx proximally. The palmer aspect of the DP is comprised of fat containing soft tissue separated by fibrous septae, commonly referred to as the "pulp".

Flexor Digitorum Superficialis (FDS) – Originates from the medial epicondyle, humero- ulnar head, and medial aspect of the radius, travels within the intermediate compartment through the carpal tunnel, and inserts on the shaft of the middle phalanx. Excursion of the FDS flexes the wrist, PIP, and MCP joints.

Flexor Digitorum Profundus (FDP) – Originates from the anteromedial ulna and interosseous membrane, travels within the deep compartment through the carpal tunnel, and inserts on the base of the distal phalanx. Excursion of the FDP flexes the wrist, DIP, PIP, and MCP joints.

Flexor Zones (Verdan's Classification)

- Flexor Zone I - Distal to FDS insertion on the middle phalanx
- Flexor Zone II – Extends distally from the A1 pulley up to and including the insertion of the FDS on the middle phalanx.
- Flexor Zone III – Distal aspect of carpal tunnel to A1 pulley
- Flexor Zone IV – Carpal Tunnel
- Flexor Zone V – Proximal to carpal tunnel

Active Range of Motion (AROM) – degree of a single joint's motion achieved by related muscle groups without external assistance. i.e. flexion arc of the distal interphalangeal joint by excursion of the flexor digitorum profundus.

Total Active Range of Motion (TAM) – sum of flexion of the MCP, PIP, and DIP joints minus the loss of extension of each of these joints.

Static Two-Point Discrimination (s2PD) – a neurological assessment that tests a patient's ability to differentiate two separate non-moving tactile stimuli in fixed proximity. This varies anatomically due to both receptor density and field size.

Dynamic Two-Point Discrimination (m2PD) – A neurological assessment that tests a patient's ability to differentiate two separate moving tactile stimuli in fixed proximity.

Odds-Ratio (OR) – A relative probability of an outcome comparing different exposures.

Current Recommendations

While survival of replanted digits reached 80% and greater in the 1980's,[9] during this time period, functional outcomes for amputations through flexor tendon zone II were typified by tendon adhesions, bony non-union, and poor sensory return.[10] This has factored in to single finger zone II injuries often being characterized as a relative contraindication to replantation/revascularization,[11-15] while others go further and list single finger amputations as an absolute contraindication to replantation.[4,16] William L. White's paper "Why I hate the Index finger" was published in 1980, 15 years after the first successful digital replantation by Komatsu and Tamai. It is a cornerstone in the animus directed towards the replantation of the index, which persists in some quarters to the present day, with contemporary references still listing the index as an especially poor candidate for replantation.[6,7,17] A stiff, cold-intolerant, chronically painful replanted or revascularized index finger interferes with useful activity of the non-injured remainder of the hand, is obstructive in rehabilitation, rote with complications, and ultimately may become a liability and an indication for secondary amputation.[3] The present manuscript re-evaluates this perspective with review of current evidence.

Biomechanics

To understand the implications of hand trauma to the index finger, we must first understand the functional role it plays in hand prehension. The index finger is a major contributor to motion in precision pinch (distal pulp opposition with DIP flexion of thumb and index) and oppositional pinch (pulp opposition with dip extension of thumb and index). It serves as a stable post to the thumb in key pinch (thumb adduction to index middle phalanx).[18-20] The index metacarpal is part of the hand's lever arm in directional and power grip, providing mechanical advantage in pronation and supination by a lengthening of the external fulcrum.[21,22]

It is also key to understand the altered prehensile function of the hand at various levels of index finger amputation, in order to weigh functional deficits relative to functional outcomes of replanted index fingers. Index amputations proximal to the distal interphalangeal joint result in the typical patient transitioning to using the long finger for precision and oppositional pinch.[19] Ray amputations showed objective functional deficits decreasing overall hand function in power grip, key pinch, and supination by 20% and pronation by 50%. This, however, is accompanied by patients' subjective sense of improved hand function due to the index previously being an obstacle16 to precision movements since those functions are transferred to the long finger.[19,22,23]

Outcome Measures

Current Survival Rates

Single finger amputations distal to FDS insertion (Zone I) are a widely accepted general indication for replantation.[5,7,13,23,24] For the purpose of this review, we will focus on new evidence regarding Zone II index amputation injuries and replantation.

Current replantation success rates are reported between 61-92% with relatively higher success rates seen in Asian centres compared to North American.[25-30] Success rates vary significantly with the mechanism of action. A 2006 meta-analysis reported successful replantation rates of 91.4, 68.4 and 66.3% for guillotine, crush and avulsion mechanisms, respectively.[30,31] A 2016 meta-analysis solidifies a crushing or avulsion mechanism of injury as a poor prognostic factor for replantation survival with a significant 5.01 OR for guillotine versus avulsion, and 2.86 OR for guillotine versus crush injuries.[32] In 2017, Zhu et al. analyzed the results of 291 amputations and subdivided mechanism into blade, saw, crush, and avulsion injuries finding survival rates of 97.6, 87.4, 83.3 and 82.2, respectively. Interestingly, although significant results for survival based on mechanism of injury persisted, the survival gap narrowed with saw injuries being similar to crush and avulsion.[26]

Dec's meta-analysis suggested little difference in survival based on level of injury except when comparing distal phalanx amputations at 77.7% to more proximal injuries of the DIP, MP, PIP, and PP at 87.7 – 88.9%. There was, however, poorer survival rates for index replants at 75% versus long, ring and small fingers at 82.8 – 88.9%.[30] The finger distribution of crush and avulsion injuries, with more extensive tissue damage, were not elucidated in Dec's study and could be a possible confounder in individual finger survival rates. Findings of Waikakul et al. complicate the discussion of level of injury where the incidence of avulsion, degloving, and extensive crush injuries accounted for 63% of PIPJ injuries with poorer survival and functional outcomes.[27]

Primary evidence regarding smoking and finger replant survival has produced some conflicting results. In 2000, Waikakul et al. evaluated the impact of smoking and found a significant impact with a replant survival of 61.1% for smokers versus 96.7% for non-smokers.[27] More recent studies have produced conflicting data concerning smoking as an independent risk factor for reduced replant survival. Ji-Yin et al. (2015) and Nishijima et al. (2016) found no increased risk of replant failure with smoking.[33,34] While studies by Yin et al. (2015) and Breahna et al. (2016) reported significantly poorer results with smoking.[35,36] Zhu et al. (2017) conducted the first dose-response study of smoking and replant failure, dividing patients into mild (<10/d), moderate (10-20/d), and heavy (>20/d) smokers. They found that mild and moderate smoking did not increase the risk of replant failure but that heavy smoking reduced the survival rate to 76.2% versus 92.4% for non-smokers.[26] Collectively, these results suggest that the conventional wisdom that smoking results in poor outcomes is more nuanced and should be considered in the context of other prognostic factors.

Range of Motion

Impaired flexion after single finger replantation of a Zone II amputation has been cited as a major limitation to functional outcomes.[25,37] The average flexor ROM in the index finger is 68°, 104° and 80° for the DIPJ, PIPJ and MCPJ, respectively.38 Chao et al determined the required index joint flexions for precision hand functions. Tip pinch required 25/50/48° (DIPJ/PIPJ/MCPJ), oppositional pinch required 0/25/48°, and key pinch required 20/35/20°. In order for the injured index to perform these precision movements, it needs to regain 37, 48, 60% of the average AROM, respectively.[38,39]

Inferior ROM outcomes have been demonstrated for Zone II replants vs. Zone I replants. Urbaniak reviewed 59 cases of single finger amputations and found that replants proximal to the FDS insertion had, on average, 35° PIPJ ROM as compared to 82° for replants distal to the FDS insertion. In 2002, Ross reviewed 48 patients with 103 finger amputations comparing tendon function by ROM prior to any tenolysis procedures based on level and mechanism of injury. Ross found Zone II finger injuries to have an average total active range of motion (TAM) of 126°. Sharp and crush injuries had comparable TAM outcomes, 148° and 155° respectively, with avulsion injuries having poorer TAM at 109°. They also reported better AROM with dual FDS and FDP repair (136°) versus FDP repair only (111°).[40] Unfortunately, their assessment of PIP AROM was an average of all levels of injury and mechanisms, making it difficult to draw comparisons to Urbaniak. Furthermore, both studies did not distinguish Zone II ROM outcomes based on mechanism of injury. This raises the question as to whether the functional outcomes are truly representative of all Zone II injuries or are more indicative of a higher incidence of mechanisms of injury with poorer outcomes, i.e. crush vs. sharp "guillotine"-type injury.

More recent evidence published by Buntic et al. in 2008, in evaluating Zone I and Zone II index finger replants/revascularizations, classified injuries into excellent (>195o TAM), good (130-194o TAM), fair (65-129o TAM), and poor (<65o TAM). By this classification, Buntic would classify the results found by Ross as fair or good TAM outcomes. In Buntic et al.'s study, the average TAM for the 9 index Zone II injuries in his review had an average TAM of 133o with one patient obtaining excellent TAM, 3 obtaining good, 4 obtaining fair and one obtaining poor. Put another way, 8 of 9 patients obtained fair or better TAM with index replantation.[41] Chen et al. reported relatively poorer findings with 6 amputations at the level of the PIP or PP obtaining, on average, 110° TAM but with all fingers still obtaining fair TAM classification.[42] This would suggest that Zone II TAM outcomes have not significantly improved with respect to the studies of Urbaniak and Ross. Future studies should evaluate functional outcomes by the mechanism of injury at each flexor zone level measuring both individual joint ROM and TAM. This would clarify whether the poorer Zone II outcomes are due to mechanism or level of injury. More importantly, it will improve clinical decision making by determining whether there is a reasonable chance of individual joints obtaining the prerequisite flexion required for index precision functions.

Further consideration should be given to the consequences of a stiff index finger on the function of the non-traumatized finger. In 1925, Bunnell first explained one effect of finger stiffness on adjacent fingers (later named the quadriga effect by Verdan), namely, a reduction in overall hand function greater than the deficit produced by an individual stiff finger.[43] This quadriga phenomenon arises from limitation of adjacent fingers' FDP excursion caused by stiffness or adhesions of the traumatized finger. This is due to the shared FDP muscle belly of the fingers[43,44] and general finger proximity of FDP tendon fibers, synovial sheathes, and lumbrical origins.[45,46] Baaqeel et al. studied this effect in isolated finger stiffness and found that the index had the least quadriga effect. With index stiffness, they found a TAM reduction between 9-17% with the adjacent fingers experiencing the greatest impairment. The ability of adjacent fingers to touch the distal palmer crease showed mild to no impairment.43 The limited index quadriga is attributed to less interconnections of the index's FDP musclotendinous unit and the unipennate lumbricals of the radial fingers.[43,44]

Range of motion should not be the only consideration when assessing functional outcomes. This is particularly important in the radial three fingers as sensory return has been hypothesized to be of greater importance than mobility. Arguably, this is even more critical in the case of a replanted index finger, where sensory return would need to approximate that of the long finger in order to prevent precision function bypass and functional hinderance by obstruction.[23]

Sensory Outcomes

Sensory return to the index is vital to its use in precision functions. Bypass of the index finger in favor of the long is commonly seen with poor sensory return that does not approximate that of the long finger. Whether this threshold varies significantly from patient to patient or is experienced at a specific level of sensory loss has not been established.

The American Society for Surgery of the Hand categorizes static two-point discrimination (s2PD) <6 mm as normal, 6-10 mm as fair, 11-15 mm as poor, and >15mm as protective. Dellon et al. found that s2PD of <15mm allowed patients to maintain precision grip without which unobserved objects would be dropped. The best predictor of hand function, however, was dynamic two point discrimination (m2PD) with values of m2PD <6 mm allowing patients to recognize all objects with active touch and 3 mm being considered normal.[47]

Urbaniak defined an average adult s2PD of 11.7 mm as a poor outcome.[13] Contemporary findings by Morrison et al. of 130 patients reported superior results with 90% of replants and revascularizations obtaining between 4-15 mm and an average 9 mm s2PD.[48] In 2008, Walaszek reported 56% of replanted/revascularized fingers obtained s2PD of <10 mm.[49] In 2018, Chen et al. reported on crush and avulsion amputations with an average s2PD of 10.4 mm with 5 replants obtaining <6 mm and 14 replants obtaining 6-10 mm.[42] Collectively, these results show that sensation outcomes, since the frequently referenced Urbaniak study, have improved with the majority of replants reaching fair status or better in terms of s2PD. The question of whether s2PD alone is the best metric of hand function after replantation remains. Future studies should strive to measure both m2PD and s2PD to properly assess replant function.[47]

Global Functional Outcomes of Replants vs Amputations

Although individual measures of hand function are important, a global assessment is required to compare replantation to the revision amputation alternative.

Waikakul et al. (2000) analyzed the results of 1018 amputations using the Chen et al. classification to determine functional outcomes. The Chen classification stratifies outcomes by employability, range of motion, sensibility, and strength.[50] The cumulative results are graded from I – IV, with grades I and II being considered good functional results. Grade I results indicate an ability to return to their original employment whereas grade II allows for employment but not in the patient's original profession. Based on mechanism of injury, guillotine injuries had the best results with 163 of 209 patients (78%) obtaining grade I or II as compared to avulsion, degloving, and extensive crush injuries collectively having 7 of 104 (6.7%) with grade I or II. Local crush injuries showed similar results to guillotine injuries with 454 of 633 (73%) obtaining grade I or II, however, 63% of guillotine injuries obtained grade I as compared to 35% of local crush injuries. As expected, single finger replants fared better than multiple fingers with 244 of 287 (85%) obtaining grade I or II outcomes. Unfortunately, finger bone anatomy was used to indicate level of injury instead of flexor zones. Zone II outcomes based on type of tendon repair were only conducted for local crush injuries. This leads to some ambiguity when looking at the functional grades for Zone II injuries, for it is not stated whether the middle phalanx injuries are proximal or distal to FDS insertion. Including only PIPJ, PP, and MCPJ injuries, 303 of 567 (53%) obtained grade I or II results. The results of the PIPJ are further complicated due to 122 of 195 amputations resulting from avulsion, degloving, or extensive crush mechanisms of injury.[27]

Zhu et al. studied single finger replantation versus revision amputation assessed by the Michigan Hand Outcomes Questionnaire (MHQ) separating results by finger and level of injury. The Tamai classification was used with level IV (proximal phalanx to middle phalanx FDS insertion) amputations corresponding to Zone II injuries, excluding Zone II injuries from MCP to the A1 pulley captured by level V injuries. The MHQ evaluates hand function by overall hand function, ADL, pain, work performance, aesthetics, and patient satisfaction. The individual assessments are averaged providing a final score from 0 to 100 with better performance indicated by higher scores. There was a total of 41 level IV index injuries, 15 treated with replantation, and 26 with revision. All level V index and any level IV without active MCP movement were revised with a ray amputation. The index level IV MHQ scores averaged 85.4± 12.9 and 70.7±14.5 for replantation and revision, respectively. There was a total of 31 level V index injuries, 11 treated with replantation, and 20 with revision. Level V injuries demonstrated similar results with 83.5±12.1 and 71.2±16.7 for replantation and revision, respectively. The survey was conducted one year after the initial operation and included patients who underwent secondary procedures, including tenolysis and capsulotomies with replantation patients often participating in a rehabilitation program. Crush and avulsion injuries were more frequently treated with revision amputation.[25]

Patient Reported Outcomes

To understand the impact of hand and finger injuries on subjective outcomes, a normative comparison group needs to first be established. Harth et al. determined a DASH control baseline that showed an average DASH score of 13 ± 15 in non-injured employed adults. This varied by type of employment with nonmanual occupations reporting a DASH of 9.7 ± 12.5 as compared to manual occupations with an average DASH of 15.7 ± 17.2. This difference in occupational type disappeared when considering activities specifically related to leisure activities, such as sports and music. Gender and age were also demonstrated to impact DASH scores with women and increased age having higher baseline DASH scores.[51]

While flexor Zone I amputations have long been considered good candidates for finger replantation, the same cannot be said for flexor Zone II amputations. Due to this, there are a variety of studies regarding patient reported outcomes (PRO) for various means of reconstructing the fingertip, while there is a relative dearth of studies for flexor Zone II injuries particularly with regards to the index finger. This may partly be due to the poor cost effectiveness of single finger index replantation with an incremental cost effectiveness ratio per quality adjusted life year gained more than double comparison groups.[52] Many reports regarding PRO focus instead on those revision methods such as ray amputation, primary, or secondary, with or without transposition versus primary phalanx revision. It is only with more recent studies that flexor Zone II replantations are once again being considered. Generally, however, the focus has been on objective measurements of function such as AROM and sensory outcomes. Rarely are PRO reported independently for flexor Zone II, and when found, are part of a composite objective and subjective score.

El-Diwany et al. specifically looked at single digit replantation versus revision amputation in Zone II amputations. Using Quick-DASH and the Beck Depression Inventory form, no significant difference was found between replantation and revision (Q-DASH 14.04 ± 16.74 vs 18.94 ± 19.82, p=0.477). In addition, no significant difference was found in cold intolerance, pain, esthetic satisfaction, discontinued activities, or modified social relationships.[53] El-Diwany et al. used primary revision amputation as the comparison cohort, however, often the surgical alternative for amputations involving flexor Zone II is a ray amputation. Melikyan et al. evaluated subjective outcomes of 20 ray amputations injuries using the DASH questionnaire and the visual analogue scale (VAS) for satisfaction. They further subdivided the results into index, central, and little finger ray amputations. All of the index fingers were amputated due to trauma, whereas the little finger amputations included trauma, vascular pathology, and Dupuytren's disease, and central fingers included trauma, neuromas and congenital deformities. The average DASH score for the index finger was 32.4 ± 7.9 and the average VAS satisfaction was 3.9 ± 0.2. The DASH score for the index finger was larger than that seen for other ray amputations with the central fingers having an average 29.4 and little finger 24.9. The VAS satisfaction score for central fingers and little finger were 3.6 ± 0.5 and 4.2 ± 0.4, respectively, but were not statistically significant from the index VAS.[54] Both the involvement of the dominant hand and whether the mechanism was traumatic or non-traumatic has been shown to negatively impact the DASH score55,56 despite comparable objective functional outcomes.[57,58] The negative DASH effect of dominant hand involvement was also observed for finger replantation.[59] The discrepancy between objective measures such as the Hand Injury Severity Score (HISS) score and subjective measures such as the Quick DASH were also noted by Matsuzaki et al.[60] Of the objective measurements, total grip strength best correlated with subjective outcomes[42] with other studies reporting a significant correlation of pinch strength and ROM to Quick DASH scores in thumb replantations.[61]

This could skew the Melikyan et al.'s results in comparing the index to the central and the small finger cohorts due to the inclusion of non-traumatic indications for ray amputation and varying dominant hand involvement. Furthermore, not all resections have equal subjective outcomes. Bhat et al. in analyzing ray amputations determined that secondary ray amputations after replantation and central ray amputations including transposition had higher average DASH scores (25.9 versus 13.3 and 45 versus 18.3, respectively) compared to primary ray amputation.[57]

Another consideration in evaluating subjective outcomes is the time since injury in which the DASH was administered. Kovacs et al. evaluated 1952 adult patients with severe hand trauma distal to the carpus with a HISS of >50. Their results demonstrated an average DASH score of 28.7 for severe hand trauma patients <3 years since injury, which decreased to an average DASH of 20.2 for those patients >3 years.[51,62] They theorized that this demonstrated the impact of functional adaptation over time on DASH scores. This is an important area of future investigation. Determining the impact of time dependent functional adaptation by patient vocation, leisure activity, and rehabilitation involvement would improve clinical decision making with respect to hand trauma.

Interestingly, there is a growing body of literature evaluating work compensation status and patient reported outcomes. Kadzielski et al. determined that pain and worker compensation status were independent predictors of DASH scores and account for 52% of its variability in patients with finger injuries, although pain alone accounted for 49% of variability.[63] A meta-analysis of 129 studies including 20,498 patients by Harris et al. determined an 3.79 OR of unsatisfactory surgical outcome in patients with either workers' compensation or litigation related to their injury. In many of the included studies, workers' compensation was the best predictor of poor subjective outcome even compared to diagnostic, demographic, and treatment variables.[64] Some studies have also implicated compensation status to objective outcomes, with those patients with unsettled compensation having poorer grip strength, key pinch, and oppositional pinch compared to settled compensation and those without worker's compensation.[58] In addition, worker compensation patients with flexor tendon repair were 48% more likely to have additional reoperations compared to all other payee groups.[65] Although not completely applicable to acute finger amputations, it is noted that hand and wrist patients with compensation typically have an increased number of pre-operative diagnostic testing and clinical evaluations prior to undergoing surgery.[66]

Return to Work Considerations

El-Diwany et al. also evaluated RTW and medical resource considerations. From an occupational standpoint, there was no difference in sick days used, days required to RTW, or rate of return to same occupation, but there was higher rate of revision amputations in patients on worker's compensation which could be a confounder in RTW data in this study. Flexor Zone II replantation averaged 16.5 ± 10 weeks sick leave which was not statistically significant compared to revision amputation at 15.3 ±18 weeks.[53] Peimer et al. observed that patients who underwent secondary ray amputation after replantation averaged 16 weeks of time off work (TOW) versus 9 weeks for primary ray amputation[58] with Bhat et al. reporting similar results for secondary ray amputation after failed replantation (secondary revision 15.5 versus 13 weeks primary revision).[57] Replantation patients typically had a longer duration of hospitalization (5.47± 3 days) compared to the revision amputation population (0.3 ± 0.5 days). The replantation group also required greater hand therapy follow-up compared to the revision cohort (25.5 ± 19 weeks versus 5.9 ± 10.25 weeks).[53] The study did not distinguish between the level of RTW and whether the occupational duties were the same or modified upon RTW.

This, in addition to the greater requirement for hand therapy, could reduce hours worked by replantation patients. Although El- Diwany et al. found no difference between replantation and revision groups, the association of workers' compensation with revision amputation raises some questions as to its influence on RTW time frames. Kadzielski et al. and Wong et al. both found workers' compensation status to be associated with a delayed RTW with hand injuries.[63,67] Marom et al collaborates these findings in evaluating RTW among manual workers with hand injuries. Their results demonstrated a significant contribution to delayed RTW from worker disability benefits and legal involvement. Interestingly, less education was also seen to be a significant contributor to delayed RTW but they theorized that education was acting as a proxy for biopsychosocial factors.[68] A systematic review by Shi et al. evaluating RTW in hand injuries supports this hypothesis by demonstrating no consistent association of education with delayed RTW but rather biopsychosocial factors such as low pre-injury income as a significant delayed RTW prognostic factor.[69]

Unsurprisingly, multiple studies associate greater extent of physical injury and number of operations to delayed RTW, TOW, and return to the same occupation.[67,69,70] Furthermore, occupations requiring extensive hand use such as manual labour are associated with increased TOW and decreased rates of return. This, however, is not exclusive to manual labour with any profession requiring extensive joint mobility and tactile sensation potentially at risk.[70,71]

A correlation has also been seen with DASH scores and employment status with those returning to work, same or different occupation, having an average score of 15 compared to those unable to work averaging 45. DASH, however, was found to have only a moderate correlation with HISS which demonstrated increasing predictive significance with higher scores correlating with less return to original employment.[60]

Conclusion

Summary

Single finger index amputations in Zone II should be initially considered for replantation in select circumstances. As compared to crush and avulsion injuries, guillotine injuries report better survival, ROM, and sensation. When comparing global measures of hand function, replanted guillotine injuries allowed the majority of patients to obtain Chen grade I or II results. Replanted Tamai level IV and V index fingers also showed superior MHQ functional outcomes as compared to revision amputations. If index stiffness is experienced, it has less implications for hand function due to minimal quadriga effect. Crush or avulsion mechanisms should remain a relative contraindication for single finger index amputations through Zone II. The impact of smoking on survival should be considered in terms of dose-response.

Patient reported outcomes for flexor Zone 2 injuries show comparable subjective outcomes between replantation and revision amputation with poorer DASH outcomes reported in index ray amputations, dominant hand, and workers' compensation involvement. Primary ray revision of amputations required less time away from work compared to replantation, at level revision amputation and secondary ray revision. Worker's compensation, litigation, and manual labor vocations experienced delayed return to work.

Suggested Areas of Further Investigation

Range of motion studies of replanted zone II finger amputations should consider individual joint contribution to total active motion. Range of motion should be analyzed by mechanism of injury at each flexor zone. This would allow investigation of repairs that best approximate individual joint flexion required for precision movements. Future evaluations of sensory outcomes should include both static and dynamic two-point discrimination. The sensory threshold for index bypass in precision movements should be identified and would greatly aid in clinical decision making. Establishing whether the global hand function assessments hold true for both dominant and non-dominant injuries and the impact of vocation, leisure activity, and rehabilitation involvement on function adaption over time would aid in resource management considerations.

Limitations of the Review

The cost effectiveness of replantation versus revision amputation has not been addressed in this review. To achieve good replant outcomes seen in the global assessments, patients often require subsequent surgeries and rehabilitation. The higher financial cost with moderately improved outcomes of replantation compared to revision amputation may not be justifiable within a public health care system.

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