Current trends in digital replantation—a narrative review

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Background and Objective: Digital replantation for traumatic amputation has become the standard of care with advances in microsurgical techniques and technology. While digital replantation has progressed significantly, there are still gaps in knowledge in many aspects. Some of the controversial topics in digital replantation include the indications and contraindications, anesthesia, number of vessel anastomoses, mechanism of injury, role of vein graft, distal fingertip replantation, and postoperative management. This article is a narrative review that discusses these controversies and current issues pertaining to digital replantation.

Methods: PubMed, Web of Science, and Google scholar were searched using keywords relating to "digit replantation", "amputation", and "digital replant" with the following terms: "indications", "contraindications", "anaesthesia", "survival", "vessels", "mechanism of injury", "vein graft", "outcome", and "thrombophylaxis". Relevant articles pertaining to digital replantation and deemed by the authors as current or controversial were included.

Key Content and Findings: The reported survival rates of digital replantation are high. With the advancement of microsurgical techniques and technology, the boundaries of digital replantation continue to be pushed. Various methods have been described recently to improve the success rates of difficult replants, such as strategies for venous outflow and vein grafting. However, there are still aspects of digital replantation that remain unanswered, such as the number of veins to anastomose and the thromboprophylaxis regime.

Conclusions: The review delves into controversial aspects of digital replantation, including contraindications, anesthesia, and postoperative management. Indications and contraindications will continue to evolve alongside advancements in microsurgical techniques and anesthesia. It highlights key factors influencing survival rates, such as the number of repaired vessels and the mechanism of injury. Finally, the review consolidates strategies for managing challenging digital replantations.

Keywords: Replantation; microsurgery; amputation; finger; digit

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Introduction

Background

Traumatic amputations of digits are serious injuries that affect activities of daily living and significantly reduce quality of life (1-3). These injuries often have a profound psychological impact, and are associated with depression, anxiety, lowered self-esteem, and social withdrawal (4). Traumatic amputations usually occur in young males, which result in time off work and lost income (5).

Replantation for traumatic digital amputations has progressed significantly over recent years. The first successful replantation was a thumb amputation that was performed by Komatsu and Tamai in 1968 (6). Since then, as a result of continuous refinements in microsurgical techniques and technology, digital replantation was no longer a work of a miracle, but technically feasible and had become the standard of care in most established tertiary institutions, with survival rates between 48–97% (7,8). In addition, the focus of replantation surgery has shifted significantly from solely looking at survival rates and replanted digits without sensation or function are increasingly regarded as unacceptable.

Rationale and knowledge gap

With advancement of microsurgery, the contraindications, anesthesia used, and postoperative management of digital replants should be revisited. There have been published systematic reviews and meta-analyses that identified the predictors of replant survival to be number of vessel anastomoses and mechanism of injury (7-9), but did not explore these factors in detail. Finally, the utility of vein graft in digital replants and strategies for venous outflow are scattered and this review will pool current knowledge on these topics.

Objective

Our narrative review delves into current trends, controversies, and recent updates in digital replantation, revisiting and questioning established knowledge concerning contraindications and post-operative management. Furthermore, it serves to consolidate strategies for difficult digital replants, such as the role of vein grafting and distal fingertip amputations. We also explore the relationship of the number of vessel anastomoses and level of injury, as well as the mechanism of injury and outcomes. We present this article in accordance with the Narrative Review reporting checklist (available at https://atm.amegroups.com/article/view/10.21037/atm-23-1515/rc).

Methods

The search strategy summary is presented in *Table 1*.

Key findings

Indications and contraindications

The indications and contraindications of digital replantation are outlined in many standard plastic, orthopaedic, and hand surgery textbooks. These indications and contraindications are compilation of experiences mainly from a replantation team in Vienna and pioneers of replantation (10,11). There are also multiple factors to consider before attempting replantation, which include patient's age, occupation, hand dominance, comorbidities, expected return of function, economic factors, social and cultural background (12). Despite the accumulation of data on the outcomes, in many settings it is still difficult to choose between digital replantation and a revision amputation (13). The final decision is a discussion between the surgeon and the patient, taking into account these factors and past experiences. There is little debate on indications of digital replantation. Thumb and multiple digit replantations are strong indications (14). Any traumatic paediatric amputation is considered for replantation because children have better potential for recovery with better functional outcomes as compared to adults (15). Single digit replantation distal to the insertion of the flexor digitorum superficialis (FDS) also achieve better outcomes (16).

There is more controversy on contraindications of digital replantation (17). Established contraindications include poor general condition of the patient with presence of life-threatening injuries or debilitating comorbidities, and patients who have psychotic disorders (18,19). Patient's age is a factor to consider before replantation, but it has been reported that the replant survival rate and patient's satisfactory score are comparable between elderly patients (70 years and older) with younger patients (20).

Ischemia time has been used as one of the predictors of a successful replantation (21,22). However, other studies found that ischemia time does not affect survival rates (23). Waikakul and colleagues argued that warm ischemia is tolerated in digital replantations because digits lack muscle (21). Successful digital replantations have been reported after 33 hours of warm ischemia time and 94 hours of cold ischemia time (22,23). Successful digital replantation has also been reported after cryopreservation, with a left thumb cryopreserved in liquid nitrogen for 30 days before replantation (24). Likewise, amputation of multiple segments is one of the relative contraindications mentioned in many textbooks. However, in 2006, Chinese surgeons reported a successful replantation of the hand with severance of 5 digits and palm into 17 different segments (25). The injury extended from distal metacarpal bone to the thumb and finger tips. These examples illustrate that with the advancement of microsurgical techniques, skills, and technologies, the trend in digital replantation is to constantly challenge the limits of contraindications and

Table 1 Search strategy

Items	Specification
Date of search	12 December 2022 to 12 March 2023
Databases and other sources searched	PubMed, Web of Science, Google scholar
Search terms used	"Digital"[Mesh] AND "Replant"[Mesh]
	"Finger"[Mesh] AND "Replant"[Mesh]
	"Distal replant"[Mesh]
	"Fingertip replant"[Mesh]
	"Digital replant"[Mesh] AND "Indications"[Mesh]
	"Digital replant"[Mesh] AND "Contraindications"[Mesh]
	"Digital replant"[Mesh] AND "Anaesthesia"[Mesh]
	"Digital replant"[Mesh] AND "Survival"[Mesh]
	"Digital replant"[Mesh] AND "Vessels"[Mesh]
	"Digital replant"[Mesh] AND "Mechanism of injury"[Mesh]
	"Digital replant"[Mesh] AND "Vein graft"[Mesh]
	"Digital replant"[Mesh] AND "Outcome"[Mesh]
	"Digital replant"[Mesh] AND "Amputation"[Mesh]
	"Digital replant"[Mesh] AND "Thrombophylaxis"[Mesh]
Timeframe	1968–2022
Inclusion criteria	Inclusion criteria: studies written in or translated to English. All study designs were included. Relevant articles pertaining to the challenges and technical considerations of microsurgery in liver transplantation were included. All authors attended a meeting to discuss the literature selection and obtained the consensus
Selection process	Title, abstract and full text reviews were performed independently by all authors. Some papers were identified by reviewing reference lists of relevant publications

expand indications.

Anesthesia for digital replant

In general, digital replantation is performed under general anesthesia or regional anesthesia (brachial plexus block), which provides complete paralysis and decreased anxiety; both of which are critical to the success of the replant. However, general anesthesia should be avoided in higher risk patients with multiple medical comorbidities, patients who are not fasted for surgery, and patients with prior adverse reactions. A brachial plexus block could avoid these disadvantages but also required high volume of anesthesia agent which may cause systemic toxicity (26).

Local anesthesia avoids these risks of general anesthesia. Furthermore, the surgeon can educate the patient during the surgery, check active range-of-motion of the patient intraoperatively, and make adjustments to the tendon and bone repairs (27). It has been advocated that local anesthesia could enable the patient to achieve a better understanding of the procedures and improve doctor-patient relationship (28). Local anesthesia involves a lower cost compared to other anaesthetic modalities. The local anaesthetic agents can also augment the circulation of replanted digit postoperatively by its vasodilatory effect.

In 1995, Kour and colleagues have reported 10 successful digital replantations under combination of 10 mL of lidocaine 1% and 10 mL of bupivacaine 0.5% for volar metacarpal block and dorsal ring block with sedation using diazepam (29). Recently, Huang and colleagues compared single finger replantation using local anesthesia (1% or 2% lidocaine given at volar metacarpophalangeal joint without sedation and with digital tourniquet) compared to general anesthesia (26). The waiting time and operation time for local anesthesia group was significantly shorter, with no significant difference in the success rate as compared to general anesthesia group. However, they also cautioned that proper patient selection is necessary for digital replantation under local anesthesia- patient must be mentally stable and cooperative, and only cases with estimated operation time of less than 3 hours are considered.

Wong and colleagues have further published 8 successful single-digit replantations using wide awake local anesthesia with no tourniquet (WALANT) (30). The technique is achieved using lignocaine for anesthesia and adrenaline (in 1:100,000 concentration) for hemostasis. There are previous concerns of epinephrine causing finger necrosis secondary to vasoconstriction; however there is a lack of evidence to suggest this (31). Wong and colleagues argue that the mixture of lidocaine and adrenaline provides around 10 hours of anesthesia and avoids the use of tourniquet, which causes pain and potential damage to nerves, lymphatics and muscles (32,33).

From these studies that reported successful replantations under local anesthesia, patient selection for digital replantation is a major consideration. With improvement in microsurgical techniques, the trend may be moving more towards using local anesthesia to improve patient's experience and avoid the downsides of general anesthesia.

Number of repaired vessels and survival rates

Vascular repair is the most important step in the short-term survival of a digital replant. Generally, it was thought that repair of as many arteries and veins will increase the survival rate (16,34). However, this is not always possible depending on the condition of the vessels and extended duration of operation especially in the setting of multiple digit replantation. The number of arterial and venous repairs also needs to be balanced and the advocated ratio of artery to vein repair was 1:2 by Tamai *et al.* (35).

There is still a controversy on the number of arteries and veins to achieve an efficient replantation surgery with high survival rate. Few studies have investigated the correlation between number of anastomosed vessels and survival rate at different zones, based on the classification by Tamai and Yamano (36). These studies have reported different recommendations.

In Tamai zone I, distal to the lunula, usually only one arterial anastomosis is possible and there is no debate as to whether additional arterial anastomosis increase survival rates. Lee and colleagues have reported that repairing of vein resulted in higher survival rate compared to external bleeding method (37). However, Matsuda *et al.* and Chaivanichsiri *et al.* have reported no statistically significant difference between survival rates with anastomoses of no veins, one vein, and two veins (38,39). These authors did not specify the methods used to relieve venous congestion in patients with no vein repaired in their study.

In Tamai zone II, which is proximal to the lunula and distal to the distal interphalangeal joint (DIPJ), Lee and colleagues reported that the ratio of equal or greater number of veins repaired to arteries repaired improved survival outcome. In patients with one artery repaired, repairing of one vein results in significantly higher survival rate compared with no vein repaired, but the number of veins repaired did not significantly influenced survival rate. In patients with two arteries repaired, survival rate was higher when two or more veins were repaired. These results were similar to that reported by Matsuda et al, where all the patients with zone II amputations had one arterial repair; at least one vein anastomosis increased the survival rates, but additional vein repairs did not.

In Tamai zone III, which is proximal to the DIPJ and distal to insertion of FDS, Lee and colleagues found that the more arteries repaired the higher the survival rate of replanted digits. They also reported that equal number of arteries and veins repaired was also important, but venous congestion was not as common. On the other hand, Matsuda et al reported that the survival rate increased significantly when two or three vein repairs. They did not correlate this with the number of arterial repair.

In Tamai zone IV, which is proximal to the insertion of FDS and distal to the metacarpophalangeal joint, a similar finding of higher survival rate with more arteries repaired was reported by Lee and colleagues. They also found that repair of two veins was needed to achieve good results. However, Matsuda and colleagues found no significant difference in survival rates with one vein versus two or three vein anastomoses.

In summary, the inclination is moving towards treating each zone differently based on the vascular anatomy. Consolidating the above evidence, we believe that for digital replantation involving Tamai zone I, venous repair may not be feasible and some method of relieving venous congestion is sufficient. For zone II, one vein repair is necessary. For zones III and IV, more vein repairs result in higher survival rate. In addition, repair of both arteries in zones III and IV improves survival. Future studies should compare the survival rates at different zones as the vascular anatomy is different in each zone to reach a consensus.

Mechanism of injury and outcomes

Mechanism of injury had been identified as one of the factors that influence survival rate of digit replantations. A meta-analysis showed that replantations of guillotine amputations resulted in a survival rate of 91.4%, compared to that of crush amputations (68.4%) and avulsion amputations (66.3%) (40).

The success of digital replantation hinges not only on the survival rate but also on the long-term functionality of the replanted digit. Avulsion type amputations are often cited as having poor functional outcomes, with Urbaniak advocating revision amputation for complete finger avulsion amputations (16,41). A meta-analysis also revealed that the two most important predictors of hand function following digital replantation were level of injury and mechanism of injury (42). Patients with crush or avulsion injuries had poorer 2 point discrimination (2PD) and Disabilities of the Arm, Shoulder, and Hand (DASH) scores, compared to patients with guillotine type amputations.

While it is generally accepted that replantation of crush and avulsion type amputations result in lower survival rates and functional outcomes as compared to guillotine type amputations, a systemic review showed that outcomes after replantation of avulsion type amputations are better than historically perceived (43). Based on the findings of this review, the total active arc of motion (TAM) for replanted digits with avulsion injuries was measured at 174°, falling within the "fair" range according to the ASSH TAM scoring. However, considering that many of these digits also underwent DIPJ arthrodesis, the TAM score is considered quite functional. Also, the 2PD of replanted avulsed digit achieves protective sensation and similar outcomes to digital nerve repair. Considering these compelling results, it is advisable to offer replantation as a viable option for avulsion-type amputations.

Role of interposition vein graft for vessel anastomosis

Historical concerns surrounding interposition or bridging vein grafts for arterial anastomoses included a heightened risk of technical failure and thrombogenic response (44,45). With the advancement of microsurgical techniques, recent publications have shown that the survival rates of replantation with and without interposition vein graft are similar (46-49). Vein grafts for digital replantation are often harvested from volar hand, wrist, or dorsum foot. Vein grafts provide a reliable method of tension-free arterial anastomosis, and are mainly utilized in (I) relatively long segment arterial damage, (II) large zone of injury (such as crush or avulsion type amputations), (III) thumb replant, (IV) distal replant.

Barbato and Salsac advocated for the use of vein grafts for arterial anastomosis when the proximal arterial thrombosis exceeds 1 cm under microscopic examination (50). Molski (51) reported a survival rate of 88.9% for replantations after crush and avulsion injuries, utilizing vein grafts in reconstruction of the vessels. Hyza and colleagues reported a 100% survival rate with good functional outcomes in six cases with replantation of avulsion type amputations, after radial resection of damaged vessels and vein grafting (52). Multiple studies have also advocated for vein grafts in replantation of avulsion type amputations (53-55).

Interpositional vein grafts have also been used in thumb replantations, where they are used to bridge the ulnar digital artery or radial digital artery to the dorsal branch of the radial artery in the anatomical snuffbox. Direct anastomosis of the thumb digital arteries is difficult due to the orientation and pronated position of the thumb. Using vein grafts, the direct line of anastomosis from the ulnar digital artery of the thumb to the radial artery in the anatomical snuffbox allows the hand to be easily positioned (56). Furthermore, the microsurgical anastomosis between the vein graft and either artery or vein of the amputated part can be performed before osteosynthesis on the back table with greater ease (57,58).

Using long interpositional vein grafts, a study showed that the survival rate of fingertip replantation was higher, even when performed by young, relatively inexperienced surgeons (59). Vein grafting has been shown to be a reliable technique in fingertip or distal replantations, with no significant difference in survival rates (47,58).

Strategies for venous drainage in distal replantations

Distal fingertip replantations are technically challenging. Nevertheless, a systematic review has shown high survival rates of 86% (48). One of the main challenges in distal replantations is the venous anastomosis, as the vessel wall is thin, and prone to collapse (60). Although the repair of vein improves survival in distal replantations, it is not always possible. Some of the more well established methods to relieve venous congestion include external bleeding, arteriovenous anastomosis, and use of leeches (48).

Another less commonly known technique to relieve venous outflow is pocketing of the replanted fingertip. This method involves de-epithelizing the pulp of the amputate, followed by anchoring the replant onto a suitable de-epithelised location. This so-called dermal pocketing may be to an adjacent digit or to the palm after flexing the digit or in an abdominal pocket. The replanted digit is then separated from the pocket divided 2–3 weeks later once venous return by neovascularization is re-established. Puhaindran and colleagues reported a survival rate of 85% using dermal pocketing in the palm with microsurgical repair of digital arteries, and advocated that this is a good salvage method to increase survival in distal replant in patients where no veins are available for anastomosis (61). Arata and colleagues further applied the pocketing method for fingertip amputations without arterial and venous anastomosis, and reported survival rate of 81% (62).

Purisa and colleagues introduced an alternative method for venous outflow using intramedullary venous drainage system (63). A perforated needle with multiple holes is introduced into the medullary cavity of the bone in the amputated part and stump for venous drainage. This needle is threaded through a Kirschner wire, which was subsequently removed. The needle serves as a bony fixation device as well. Complete survival was achieved in 88% of the fingertips.

Delayed venous anastomosis has been described by Koshima and colleagues with good results (64). In this technique, the authors performed anastomosis of the digital artery in the first stage of the digital replant. After 8–12 hours post arterial repair, the fingertip would become congested and the diameter of the subdermal vein increased to 1 mm or more. Venous anastomosis is easier at this time. The authors reported success rate of 85.7% with no cases exhibiting venous congestion after the second procedure (60).

These articles showcase the high success rates with different strategies for venous drainage. The authors' experience is that the shift is gravitating towards performing more distal digital replantations using these strategies when venous anastomosis was not possible.

Postoperative management

Immediate postoperative period is often focused on preventing vascular insufficiency. The standard postoperative care includes close monitoring of skin colour, temperature, turgor, and capillary refill time, keeping the patient well hydrated and comfortable, and ensuring a bulky, noncompressive dressing. Prophylactic antithrombotic agents are used widely following replantation surgery. Many different types of medications have been used, such as aspirin, intravenous heparin, locally applied heparin, low-molecular weight heparin, phosphodiesterase inhibitors and dextran (18,65,66). Current guidelines for the use of antithrombotic agents post-replantation is lacking.

A systematic review of comparative studies that examined the use of perioperative thromboprophylaxis in digital replantation reported that the clinical efficacy and safety of these agents remain equivocal (67). Only one study in this systematic review reported significant difference in survival rate when continuous heparin infusion was used to reach a target activated partial thromboplastin time (aPTT) between 51 to 70 seconds (survival rate of 91.2%), as compared to patients treated with 12,500 units of intravenous bolus heparin therapy (survival rate of 59.3%) (68). Nishijima and colleagues found no difference in the replant survival rate with different doses of heparin (69). Other studies comparing other types of thromboprophylactic agents have shown no statistical significance in the digital survival rate. Some studies demonstrated a higher incidence of complications with heparin infusions, which include venous congestion, thrombosis, haematoma, and requirement for blood transfusion (69,70). The utility of thromboprophylaxis remains indeterminate in replantation surgery.

Another topic of debate is the implementation of caffeine- and chocolate-free diet in the postoperative period. Caffeine and chocolate are also avoided post-free tissue transfer in many centres (71). This is based on the assumption that caffeine or chocolate contribute to vasospasm (72). Noguchi and colleagues found that caffeinated coffee intake significantly reduced finger blood flow and increased vascular resistance of the finger vascular bed in healthy subjects, but also enhanced post-occlusive reactive hyperemia of the finger (73). Other studies have shown that caffeine leads to vasodilation via the nitric oxide pathway (74,75). The effect of caffeine and chocolate on microsurgical outcomes remains to be elucidated. Many of these postoperative protocols remain anecdotal. There is a growing tendency to challenge these protocols.

Limitations

This review is not a systematic review and may not encompass all available empirical data for such subtopic. The authors have reviewed as many relevant publications and identified a few controversial and updated topics, which are not exhaustive.

Conclusions

It has been 45 years after the first digital replantation was performed and we have gained much knowledge from the

Table 2 Summary of current trends or controversies in digital replantation

Issues	Current status	
	Generally agreed	Debatable/newer evidence or methods
Indications	• Thumb (17), multiple digit (17), paediatric (18), single digit distal to flexor digitorum superficialis (FDS) insertion (19)	• Amputation proximal to FDS insertion
Contraindication	• Life threatening associated injuries, debilitating comorbidities, severe psychotic disorders (21,22)	• Elderly (23), prolonged ischaemia time (21-27), multi-segmental amputation (28)
Anaesthesia	• General anaesthesia and/or regional anaesthesia • Local anaesthesia with comparative survival rates (26,29)	• WALANT (30,32,33)
Number of vessels to repair	• Repair as many arteries and veins (16,34) • Ratio of artery to vein 1:2 (35)	• Minimum number of veins to be repaired is specific to each zone of amputation for optimal survival (37-39)
Mechanism of injury	• Digital replantations for crush and avulsion type amputation generally result in lower survival rates and worse outcomes compared to guillotine type amputation (40,42)	• Replantation of avulsion type amputation should still be attempted and outcomes are better than historically perceived (43)
Role of interpositional vein graft	• Vein grafts may be used for vessel anastomosis in replantation	• Survival rates of replantation with or without interpositional vein graft are similar (49-49) • Indications of using vein grafts include long segment arterial damage (50), wide zone of injury (51-55), thumb replant (56), and distal replant (47,58,59)
Method of venous outflow in distal replants	• External bleeding, arteriovenous anastomosis, leech (48)	• Subcutaneous/dermal pocketing (61,62), intramedullary venous drainage (63), delayed venous anastomosis (64)
Role of thromboprophylaxis	• No consensus on thromboprophylaxis regime	• No significant difference in survival rate with any reported thromboprophylactic agent (67-69)
Post-op diet restriction	• No consensus on post-op diet	• Caffeinated foods cause vasodilation or post-occlusion hyperaemia of digit instead of vasospasm (73-75)

WALANT, wide awake local anesthesia with no tourniquet.

experience of surgeons all around the world. There have also been significant advances in microsurgical equipment, skills, and technology. We have discussed and summarised the current trends or controversies in digital replantation in *Table 2*. The functional outcomes have generally improved. With these improvements, the trend of digital replantation is towards pushing the boundaries of contraindications, expanding the indications, and challenging the established anecdotal archaic protocols backed by little scientific evidence.

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