Original articles

Effects of external bleeding and hyperbaric oxygen treatment on Tamai zone 1 replantation

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Abstract
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Introduction: Tamai zone 1 replantation poses a challenge due to the very small size of the vascular structures; often there is no vein for anastomosis. Replantation may have to be done with only an arterial anastomosis. In our study, we aimed to evaluate the success of replantation by combining external bleeding and hyperbaric oxygen treatment (HBOT) in Tamai zone 1 replantation.
Methods: Between January 2017 and October 2021, 17 finger replantation patients who underwent artery-only anastomosis due to Tamai zone 1 amputation received 20 sessions of HBOT with external bleeding after the 24th postoperative hour. Finger viability was assessed at the end of treatment. A retrospective review of outcomes was performed.
Results: Seventeen clean-cut finger amputation patients were operated on under digital block anaesthesia with a finger tourniquet. No blood transfusion was required. In one patient, complete necrosis developed and stump closure was performed. Partial necrosis was observed in three patients and healed secondarily. Replantation in the remaining patients was successful.
Conclusions: Vein anastomosis is not always possible in fingertip replantation. In Tamai zone 1 replantation with artery-only anastomosis, post-operative HBOT with induced external bleeding appeared to shorten the hospital stay and was associated with a high proportion of successful outcomes.

Introduction

After the successful digital artery repair in 1965 and the first successful total amputated thumb replantation in 1968, fingertip replantation began to be performed with the development of microsurgical techniques and instruments.[1,2] Replantation is the gold standard in finger amputations. The best aesthetic and functional results can be achieved with successful replantation. Fingertip injuries pose a challenge due to the very small size of the vascular structures and often there is no vein for anastomosis. Tamai zone 1 replantation refers to the replantation level distal to the base of the nail, and artery-only replantation is predominantly performed.[3] Successful artery-only replantations were reported in 1972 and 1973.[1,4] Numerous techniques have been described to provide venous flow in patients undergoing artery-only replantation. These techniques use medical or mechanical leeches, partial or total nail bed removal, and/or fish-mouth incision.[5] With these techniques, however, the hospital stay of the patients is prolonged.[6–8] Improved approaches would shorten recovery and accelerate the return of the patients to work.

After artery-only replantation, ischaemia-reperfusion (IR) injury is inevitable. This can cause tissue microcirculation insufficiency and necrosis after prolonged ischaemia, which adversely affects the viability of the amputated finger and may lead to partial or total necrosis.[9] In addition to the damage caused by ischaemia in the amputated tissue, tissue damage can continue after reperfusion. Tissue microcirculation insufficiency and necrosis due to reperfusion after prolonged ischaemia is defined as 'IR injury'. In Tamai zone 1 replantation, both IR injury and inability to perform venous anastomosis negatively affect the success of replantation. Hyperbaric oxygen treatment (HBOT) has been used in replantation of the extremities and has been found to be effective.[9,10] Therefore, in our study, we aimed to evaluate the success of replantation by combining external bleeding and HBOT in Tamai zone 1 replantation.

Methods

Senior hospital management have confirmed that a retrospective case series of this nature is out of scope for

ethics committee review in this jurisdiction. All patients gave permission for their data to be reported.

Records were reviewed for patients who underwent finger replantation with artery only anastomosis after Tamai zone 1 amputation and who received post-operative HBOT. Between January 2017 and October 2021, 17 finger replantation patients were managed in this way. Patients who underwent multiple finger replantation, had diabetes, additional trauma, and did not complete HBOT sessions were excluded from the review. Since venous anastomosis could not be performed, external bleeding was performed with an incision made from the pulp. Patients received HBOT on the 1st postoperative day since the surgery time and recovery after anesthesia were long. Patients were discharged on the first postoperative day but returned for daily HBOT and induced external bleeding. Hyperbaric oxygen treatment (100% oxygen at 243 kPa [2.4 atmospheres absolute] for 90 minutes) was administered over 20 sessions. The demographic characteristics, amputated finger and complication data of the patients were noted. This was not a prospective study and there was no control group. To mitigate this limitation we compared outcomes with case series in the literature in which artery-only anastomosis was performed and HBOT was not administered. All patients reviewed received 20 sessions of HBOT and there were no patients with missing sessions.

SURGICAL PROCEDURE

The amputated finger was wrapped with saline-soaked gauze and kept in appropriately cool conditions (approximately +4°C) until the patient was taken into surgery. Replantation was performed under digital block anaesthesia. After a finger tourniquet was applied, the wound was evaluated under loupe magnification. Adequate debridement was performed, and blood vessels were dissected. The tourniquet was then released, and the blood flow of the digital arteries was checked. The amputated finger was prepared for anastomosis. Bony fixation was performed by using one or two Kirschner wires in all patients. These were removed in all patients at postoperative 4th week after evaluation by hand radiography. Tendon repair was not required, because all the injuries were Tamai zone 1 amputation. Central digital artery and digital nerve anastomosis were performed with 11-0 nylon sutures. The skin edges were loosely sutured to allow bleeding and prevent venous congestion. During the operation, 5,000 IU heparin was given and 100 mg acetylsalicylic acid was given in the follow-ups. Oral antibiotics were given to the patients for one week in the postoperative period.

Table 1
Numbers of patients by affected finger and hand

Hand / finger	2nd	3rd	4th	5th
Right hand	2	4	3	1
Left hand	1	3	2	1

Results

Seventeen clean-cut finger amputation patients were operated on under digital block anesthesia with a finger tourniquet. The numbers of patients by digit and hand are reported in Table 1. Eleven patients were male and six were female. The mean age was 31.2 (range19–46) years. No blood transfusion was needed, bleeding was controlled after each application of HBOT. The estimated amount of bleeding was 200–400 ml, with an average of 270 ml. At the end of 20 sessions, the patients were examined and subsequently followed up for an average of 21 months (range 8–33). In one patient, complete necrosis developed and stump closure was performed. Partial necrosis was observed in three patients which healed secondarily. All other patients had successful replantation examples of which are shown in Figures 1 and 2. No soft tissue infection or osteomyelitis was

Figure 1
Left hand, second finger Tamai zone 1 amputation (A) and the same patient at the fourth postoperative month (B)

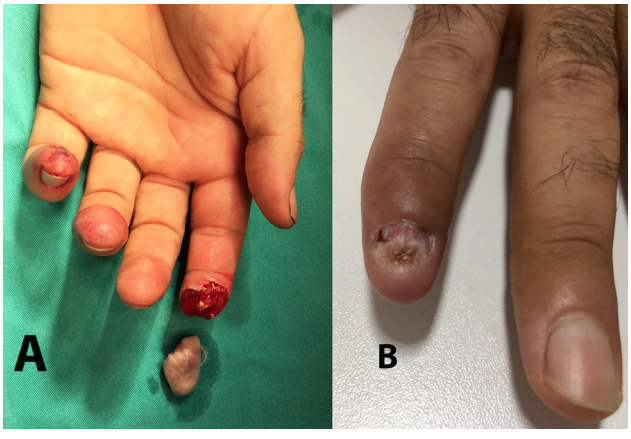

Figure 2
Left hand, third finger Tamai zone 1 amputation (A) and the same patient at the eighth postoperative month (B)

observed. Since the amputation was distal from the distal interphalangeal joint, the range of motion for functional evaluation was not evaluated. Fingertip sensation began to return from the sixth month. No loss of sensation was observed in long-term follow-ups.

Discussion

In fingertip amputations, apart from replantation, reconstruction can be performed with composite grafts, and local or free flaps.[11,12] The aim in fingertip amputation surgery is to preserve the length and sensory innervation of the finger and to ensure its function. Although replantation is the best option in fingertip amputations, reconstructive surgeons may avoid replantation due to the difficulty of the technique and postoperative follow-up. Vessels are small, and the surgical field is narrow and deep.[13] Vascular repair can be performed with the dorsal or volar approach.[14]

In artery-only replantation, venous insufficiency is inevitable and venous flow must be provided with different techniques. In one study where artery-only anastomosis was performed, heparinized saline was applied topically to the gap in the Tamai zone 1 suture line. The authors reported that 93% of the replanted fingertips survived.[15] Nevertheless, they recommended performing vein anastomosis if possible. In another study in patients who underwent distal phalanges replantation, adequate vein width was obtained 8–12 hours after arterial anastomosis and vein anastomosis was performed with a second operation.[16] The disadvantage of this technique is that it is a two-stage procedure and if adequate arterial flow is not achieved in the first operation, vein anastomosis may not be achieved in the second operation.

Mechanical and medical leech therapy can also be applied. In medical leech treatment, the risk of wound infection increases and the patient or family members may have difficulty during the application.[17] In the mechanical leech technique, an angio-needle is anastomosed to the branch of the central digital artery. The catheter is removed gently after the circulation of the replanted finger is established. A chemical leech procedure can also be used. After making a 2 mm incision over the fingertip, heparin is injected subcutaneously and systemic heparin and dextran-40 are given.[7] A high success rate is obtained using this technique. Adequate bleeding is also obtained by nail plate removal. The nail plate can be removed totally or partially.[6,8,18] In these studies, the length of hospital stay was extended up to 14 days, and in our study, the patients were discharged on the first postoperative day. The shortening of the hospitalisation period has positive effects both in terms of health expenses and patient psychology.

In a study by Han et al. the average duration of neovascularization was 7.6 days in patients who underwent artery-only anastomosis and postoperative external bleeding.[19] They also observed that the duration of external bleeding was shorter in young and less injured patients.

In the anatomical study by Nam et al. the central artery was divided into three types. In type 1, only one dominant artery branched off from the distal transverse palmar arch. If the fingertip had two dominant arteries, it was classified as type 2 and if the fingertip had three and more branches, it was classified as type 3.[20] They observed that type 3 was the most common type. If there are two or more arteries one can be used for venous anastomosis. After the digital artery anastomosis, another digital artery can be used for anastomosis to the vein of the proximal stump, if it is possible. We performed digital nerve anastomosis in all cases. Since the neural network of the region is dense in fingertip replantation, adequate innervation is provided even if nerve anastomosis is not performed.[21]

Ischaemia-reperfusion injury is one of the major problems in replantation surgery. Many different mechanisms play a role in IR injury. Reactive oxygen species (ROS) such as superoxide and hydroxyl radicals are thought to be the main mediator of cell damage. These cause DNA damage, lipid peroxidation and cell membrane damage.[22] There are protective antioxidants such as glutathione, superoxide dismutase (SOD) and catalase. However, if ROS production is too high these antioxidants may be overwhelmed. Xanthine oxidase and neutrophils are sources of ROS production.[23] Reactive oxygen species trigger migration of neutrophils to the injury zone and initiate inflammation. After reperfusion, migrating neutrophils synthesize greater quantities of ROS, contributing to reperfusion injury. Apoptosis is also seen in IR injury. Nitric oxide (NO) competes with oxygen for binding to cytochrome c oxidase which has higher affinity for NO.[23] This pathway induces apoptosis. In IR injury, vasoactive substances are released from the cells and disrupt the circulation of the injured tissue.

Hyperbaric oxygen treatment increases SOD activity and antioxidant gene expression.[24,25] It may also reduce neutrophil adhesion by reducing adhesion molecule expression,[26] and increase angiogenesis by promoting vascular endothelial growth factor transcription.[27] There have been no comparative studies to determine an optimal HBOT protocol in related injuries. In one study of injured hands HBOT was given five days a week beginning 24 hours after replantation with improved survival of the compromised tissues.[9] In another study of finger replantation HBOT was started on the first postoperative day,[10] while others have started HBOT within the first 24 hours after replantation in hand injuries. We started HBOT on the first postoperative day, and utilised 20 treatments; a higher number than some studies which we nevertheless considered appropriate because no vein anastomosis was performed. Ideally, studies comparing different HBOT regimens could be conducted to derive an optimal protocol. Care should be taken about complications during HBOT. Possible complications include seizure, reversible myopia and barotrauma to ears, sinuses or lungs.[9,28]

This is the first publication describing HBOT in fingertip amputations. In our study, hospital stay was shortened after HBOT was combined with induced external bleeding, and replantation was successful in 16 (94%) of the patients. Total necrosis was observed in only one patient. In our previous study comparing patients with and without vein anastomosis in fingertip replantation, the success rate was 77.3% (41/53) in patients who did not have vein anastomosis.[29] Given the observational nature of the present report, no firm conclusions can be drawn from this comparison. However, use of HBOT seemed associated with shorter hospital stay and better graft survival in the present study. In other approaches without HBOT, it is not possible to discharge the patients on the first postoperative day and the surgeon needs to allocate more time to the patient. This time is of great importance for microsurgeons who are busy performing long and challenging surgical procedures.

We acknowledge the lack of a contemporaneous control group or randomisation, and the small cohort of patients, as limitations of the study.

Conclusions

Vein anastomosis is not always possible in fingertip replantation. In our clinical experience it appears that HBOT with induced external bleeding shortens the hospital stay and increases the success of replantation In Tamai zone 1 replantation with artery-only anastomosis.

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