Intramedullary Venous Drainage System for Distal Fingertip Replantations

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Abstract: The number of venous anastomoses performed during fingertip replantation is one of the most important factors affecting the success of replantation. However, because vessel diameters decrease in the zone 1 level, vessel anastomoses, especially vein anastomoses, are technically difficult and, thus, cannot be performed in most cases. Alternative venous drainage methods are crucial when any reliable vein repair is not possible. In the literature, so many artery-only replantation techniques have been defined, such as arteriovenous anastomoses, forming an arteriovenous or venocutaneous fistula, manual milking and massage, puncturing, and external bleeding via a fishmouth incision and using a medical leech. It has been shown that, in distal fingertip replantations, the medullary cavity may also be a good way for venous return. In this study, we introduce an alternative intramedullary venous drainage system we developed to facilitate venous drainage in artery-only fingertip replantations. The results of 24 fingertip replantations distal to the nail fold by using this system are presented with a literature review.

Key Words: fingertip replantation, Tamai zone 1 amputation, intramedullary venous drainage, artery-only fingertip replantation

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Distal fingertip amputations are the most frequent amputation injuries of the upper extremity.[1] Advances in microsurgery techniques have made the replantation of these injuries possible.[2]

The distal phalanx is divided into zone 1 (the area between the nail fold and the fingertip) and zone 2 (the area between the nail fold and the distal interphalangeal joint [DIP]) according to the Tamai distal phalanx amputation classification (Fig. 1).[3] The number of venous anastomoses performed during fingertip replantation is one of the most important factors affecting the success of replantation.[4] However, because vessel diameters are very small in zone 1, vessel anastomoses are technically difficult and venous anastomoses cannot be performed in most cases.

Alternative venous drainage methods are necessary when a reliable vein repair is not possible. There are numerous reports of artery-only replantation techniques; these studies have suggested various methods for venous drainage, including formation of arteriovenous anastomoses or arteriovenous or venocutaneous fistulas, manual milking and massage, puncturing, and external bleeding via a fishmouth incision and using medical leeches.[5–9] In distal fingertip replantations, the medullary cavity may also serve as a good way for venous return.[10,11]

In this study, we introduce an alternative intramedullary venous drainage system we developed to facilitate venous drainage in artery-only fingertip replantations. The results of 24 fingertip replantations distal to the nail fold by using this system are presented with a literature review.

PATIENTS AND METHODS

Twenty-four fingertip replantations were performed on 22 patients between 2008 and 2013. All amputations were Tamai zone 1 amputations, and no suitable vein could be found for repair. Replantation was performed by using the intramedullary drainage system in all patients.

The system consists of a perforated 18-gauge (G) needle used as a bridge between the medullary cavities of the amputated part and the proximal bone.

Electrical discharge machining, also known as wire erosion, is a manufacturing process whereby a desired shape is obtained by using electrical discharges. This method is primarily used for hard metals or those that would be very difficult to machine with traditional techniques. It can cut intricate contours or cavities in prehardened steel without the risk of breaking it. It is widely used in metal industry and is easily accessible in our country.

The intramedullary venous drainage system was constructed by opening multiple 0.2-mm holes in a standard 18G needle body in a circular plane, by turning 90 degrees at each 0.5 cm of the needle. This perforated needle was produced with wire erosion machine at the local industry (Fig. 2). The goal was to make these holes reach the medullary cavities of the bones in both the amputated part and the stump (distal or middle phalanx). Thus, the venous blood in the amputated part would presumably drain to the medullary cavity of the proximal bone (distal or middle phalanx) by these holes and through the needle body. The needle was used both for venous drainage and bone fixation in all of the cases.

The amputated parts were examined under the microscope after appropriate debridement, and the vascular structures were tagged with 10-0 nylon sutures.

Because the needle diameter is wide, placement of the intraosseous venous drainage system in the bone is difficult. In addition, the needle is highly fragile because of the holes located in the needle body. Because drilling the needle directly into the bone may cause breaks in the needle, a cannulated screw technique is used. After bone reduction, a 0.8-mm Kirschner wire (K-W) is passed by using the amputated bone segment as a guide. The perforated needle is placed manually over this wire by sliding and rotation movements, and after adequate insertion, the K-W is removed (Fig. 3). An additional K-W is placed when the needle does not provide sufficient stability (Fig. 4). After nail-fold repair, arterial anastomosis is performed with 10.0 and 11.0 sutures. In the cases where primary arterial repair could not be achieved, arterial repair is performed with vein grafts taken from the volar side of the wrist.

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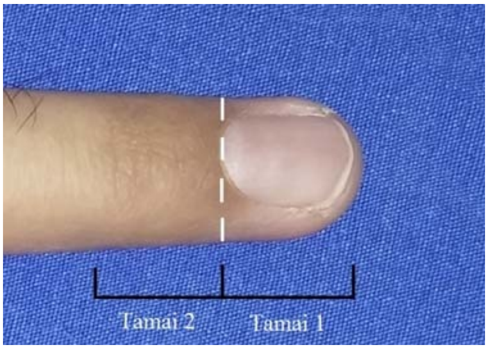

FIGURE 1. Tamai classification of fingertip amputation.

After the establishment of arterial circulation, nerve repairs are performed in cases where the proximal and distal nerve stumps were available for repair, and skin closure without nerve repair is performed in patients in whom no compatible nerves are found.

Medical treatment consisted of subcutaneous low-molecular-weight heparin (70 U/kg/d), intravenous dextran 40 (500 cc/24 h), cephazolin (1 g tid), oral pentoxifylline (400 mg tid), oral acetylsalicylic acid (300 mg qd), and an oral nonsteroidal anti-inflammatory drug. This treatment was continued until discharge.

Close monitoring of the replant was performed, with observation of capillary refill in the fingertip. External bleeding was applied when a vascular problem was suspected. In cases of any venous congestion, a 21G injector was inserted in the punched needle, and its cavity was washed by using a 10% heparin solution.

Three female and 19 male patients were operated for 24 finger amputations. The average patient age was 30 years (range, 21–46 years). The mechanism of injury was sharp injuries in 2 patients, avulsion injuries in 3 patients, and crush injuries in 17 patients.

All patients were operated under regional anesthesia. Whereas primary arterial repair was possible in 22 fingers, vein grafting was necessary in 2 fingers. The mean operation time was 85 minutes (45–330 min).

Venous drainage was provided with the intramedullary venous drainage system in all of the patients. External drainage or venous rerouting methods were not used in any patient.

Patients were evaluated in terms of the operative time, replantation success, treatment duration, and complications developed. They were questioned regarding cold intolerance.

Fifteen fingertips of 14 patients who had attended the follow-up of 12 months or more were evaluated in terms of the range of motion of the DIP, nail-fold deformities, and fingertip atrophy. In these patients, sensory evaluation was performed by 2 static point differences and the Semmes-Weinstein monofilament test.

RESULTS

The results are summarized in Table 1. Whereas complete survival was achieved in 21 (88%) of the 24 fingertips, a partial loss occurred in 1 fingertip (4%) and total loss in 2 fingertips (8%). Venous congestion developed in 4 of the 22 fingertips that had good survival in the postoperative term. Venous congestion in these 4 patients was recovered after the cavity of the needle was washed with a 10% heparin solution. There were partial/total losses because of venous congestion (Fig. 5).

In the 2 patients with total losses, circulation impairment was caused by an arterial thrombus. Although these patients were reoperated and arterial repair was performed via vein grafting, the fingertips were lost because of the recurrent arterial thrombus. In the patient with the partial loss, approximately 10% of the replant underwent necrosis. The lost part was crushed significantly more than the other parts.

No blood transfusions were necessary. Bone healing was achieved in all of the patients with successful replantation. There were no wound infections (Fig. 6).

The average duration of hospital stay was 7 days for the successful replantation group and 12 days for the failed replantation group. The average time to return to work was 80 days (70 to 110 days).

Mean 2-point discrimination was 7.3 mm (3–11 mm). Sensory assessment of the 15 fingertips of 14 patients with follow-up equal to or greater than 12 months (average, 16 months) revealed normal (green) fingertip sensation in 5 fingertips, decreased light touch (blue) in 8 fingertips, decreased protective sensation (purple) in 1 fingertip, and protective-sensation loss (red) in 1 fingertip. No significant differences in terms of fingertip sensory outcomes were found between the 5 patients who had nerve repairs versus the 9 patients who did not.

The average time for K-W removal was 6 weeks, and it was reevaluated weekly if there were no signs of bony union on x-rays. After K-W removal, the patients were told to move their fingers actively and no specific physical therapy was needed. For the assessment of the patients' joint range of motion, the total active range of motion in the replanted finger was evaluated by comparing with the same finger on the contralateral side, as described by Matsuzaki et al,[12] and found to be 98%. Fingertip atrophy was observed in 5 patients (30%), and nail-fold deformity was observed in 3 patients (20%).

Whereas 3 patients complained about cold intolerance, all of the patients were satisfied with the result.

DISCUSSION

Preservation of the nail and finger length in successful distal fingertip replantation yields cosmetically and functionally good outcomes.[13]

FIGURE 2. The perforated needle used in our intramedullary venous drainage system. The holes are 0.2 mm in diameter and are opened with a wire erosion machine.

FIGURE 3. The preoperative (above) and intraoperative (below) x-ray views of the Tamai zone 1 level thumb amputation. The arrow indicates the holes in the amputated part. An additional K-W was needed in this case for bone stabilization.

In fingertip replantations, although the goal is to perform both arterial and venous anastomoses, it is technically difficult to repair veins in replantations at zone 1. In previous reports, various methods have been reported for overcoming the venous congestion problem in cases where vein repair was not performed.[5–9]

Venous return in the long bones of humans occurs via the medullary system and the periosteal system. Whereas the medullary system provides a return to systemic circulation via a nourishing vein, the periosteal system returns blood to the systemic circulation by the muscle insertion sites. The presence of transcortical veins, which allow blood transfer between the 2 systems, has been shown.[14]

A study conducted about the effect of the medullary venous system on flap circulation demonstrated that venous drainage from the tibial bone marrow can increase the survival of amputated legs in rats, which underwent artery-only repair .[15]

Kamei et al[16] reported that the osteocutaneous free fibula flap that they transferred for mandibular reconstruction survived, despite the occurrence of vein thrombosis in the postoperative period. This may be because of the venous return provided from the medullary cavity of the transferred fibula.

Yang et al,[10] in their study, injected methylene blue mixed with isotonic saline into the digital arteries of 10 fresh cadavers and examined these fingers microanatomically. They reported that the dominant way for venous return to occur in the fingertip was via the medullary cavity of the distal phalanx. Then, they conducted a clinical study and operated on 9 patients; they used the finger medullary system to provide venous return in the crush- or avulsion-type amputations where vein repairs could not be performed. They reported that they made the medullary cavities of the distal phalanx and the middle phalanx continuous by drilling and removing the DIP joint; in this way, they experienced success in all replantations by obtaining venous return from the medullary cavity of the amputated part to the distal/middle phalanx cavities. The system we developed is basically similar to this defined system; we were successful in providing venous return through the medullary venous drainage system using a fenestrated 18G needle.

Although vascular access via the intraosseous approach has been known for more than 70 years, today, it is used when alternative venous approaches cannot be used. It is used in pediatric emergencies, such as trauma, arrest, shock, thermal injury, and diabetic ketoacidosis, to administer liquids, crystalloids, and vasoactive drugs.[17] In the literature,

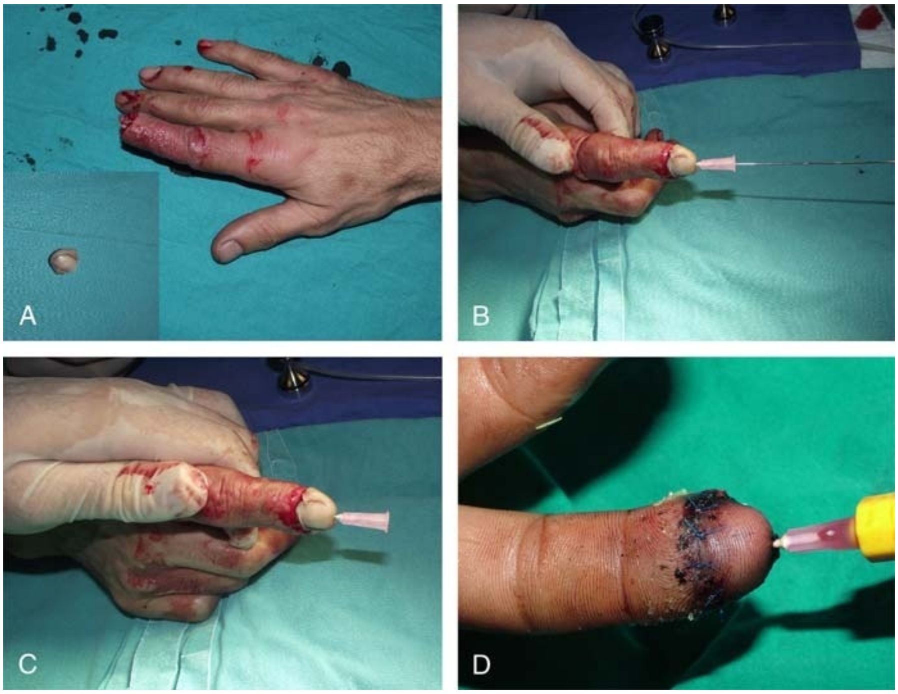

FIGURE 4. Tamai zone 1 level amputation of the index finger (A). The 0.8 mm K-W was used as a guide to the perforated needle (B). The perforated needle used for both bone fixation and intramedullary venous drainage after K-W removal (C). There are no signs of venous congestion on postoperative day 8 (D).

successful blood transfusions via the intraosseous approach have been reported in many experimental studies and case reports.[18,19] The American College of Surgeons Committee on Trauma recommended using blood transfusion via the intraosseous approach in the 2008 standard and advanced life support guideline until a compatible alternative approach is provided.[20]

We aimed to route the venous blood from the medullary cavity of the amputated part into the distal phalanx/middle phalanx medullary cavity via a perforated needle and then pass it to the systemic circulation by being absorbed in the distal phalanx/middle phalanx medullary cavity. The diameter of the cannula used in the standard intraosseous approach is similar to that of the intramedullary venous system we developed, between 18G and 20G.[21] In addition, the holes opened through the needle body expand the surface area for absorbing venous blood. In fingertip replantation, venous return is one of the most important factors affecting the success of replantation.[4,22] The fact that no problems and complications with venous congestion were seen in our cases shows the efficiency of the intraosseous venous drainage system. Additionally, decreased blood viscosity in our cases because of the anticoagulation protocol we used may have positive effects on the success of the venous drainage system.

Chen et al[11] performed artery-only replantation in 12 cases with Tamai zone 1 amputation as a result of crush injuries, and no attempt was made to provide venous return. They reported that superficial necrosis developed in 11 cases that reported venous congestion, with full recovery taking place in 1 to 2 months. The authors stated that total necrosis developed in 1 case. In addition, they reported that moderate/heavy atrophy occurred in all cases, and cold intolerance developed in 9 patients. The authors stated that venous return in their study may have been provided through the medullary venous system. In our series, no superficial or total losses due to venous congestion were seen in successful replantations. The average hospitalization period was 7.5 days (7 to 12 days). In 1 case, 10% partial loss occurred; this loss was thought to be because the part with necrosis was injured more seriously than the other parts. Previous studies have shown that venous congestion may lead to irreversible tissue damage more quickly than arterial ischemia.[4,22] In our patients, venous drainage might have occurred from the medullary cavity after a congruent bone reduction, similar to these studies. However, when we consider that the mean distal phalanx diameter of humans is 1.4 mm, the 1.2-mm area of the punched needle is wide enough to occlude this area completely.[23]

External drainage methods, such as bleeding from a fishmouth incision, bleeding by applying heparinized gauze to the nail fold, and use of leeches, can prevent venous congestion in artery-only repairs in zone 1 replantations.[2,12] However, these techniques significantly increase the work burden for the medical staff because of the need for close patient monitoring. Assessment of bleeding every 30 minutes will be necessary initially, and continuous bleeding may be required for 5 to 7 days. In addition, medical leeches may not be accepted by patients and may carry infection risks. Serious blood loss may occur especially in multiple-finger amputations, and blood transfusions may be necessary. Blood transfusion rates between 21% and 88% have been reported with the use of these methods.[8,24] However, blood transfusion should be avoided in minor operations, such as fingertip replantation. Postoperative patient care is simple in the technique we performed; we followed our patients with capillary refill observations. No blood transfusion was necessary in any of the fingertip replantations. Venous congestion, which is the main problem in this level of replantation, developed in only 4 cases and was resolved by irrigation of the needle lumen.

Zang et al[25] described venous return via a second arterial repair. The second repaired artery was ligated at a more proximal level than the amputation, and arterial backflow passed to the veins and systemic circulation. Even if this operation is a good alternative for the venous-return problem, a second digital artery may not always be found. In addition, the application of this technique is difficult and will increase the operation time.

TABLE 1. Patient Data

	Age, y/sex	Affected	Affected	Type of Injury	Vein Graft	Secondary Intervention	Nerve Repair	Return to Work, d	Hospitalization, d	Result	Static two point discrimation, mm	Semmes-Weinstein Monofilament Test	Atrophy	Nail Deformity	Cold Intolerance	DIP, Range of Motion, %
1	31/M	Right	Index	Clean cut	0	0	−	70	5	Survival						
2	31/M	Right	Index	Crush	0	0	−	75	5	Survival	10	Blue		+		100
3	34/M	Left	Middle	Crush	+	0	+	79	7	Survival	9	Blue			+	100
4	29/M	Left	Thumb	Crush	0	0	−	82	7	Survival	8	Blue	+			100
5	37/M	Left	Thumb	Avulsion	+	0	−	85	7	Survival	4	Green				94
6	28/M	Right	Middle	Crush	0	0	+	76	7	Survival						
7	43/F	Right	Index	Crush	0	0	+	72	7	Survival	6	Blue	+			100
8	25/M	Right	Index	Avulsion	0	0	−	80	11	Survival	11	Red	+		+	100
9	31/M	Right	Ring	Crush	0	0	−	74	10	Survival	8	Green				80
10	28/F	Right	Index	Crush	0	0	−	90	12	Survival	8	Blue				100
11	23/F	Left	Middle	Crush	0	0	+	84	9	Survival	5	Green		+		100
12	24/M	Right	Index	Avulsion	0	0	+	82	7	Survival	6	Green				90
13	17/M	Right	Thumb	Clean cut	0	0	−	76	9	Survival						
14	33/M	Right	Index	Crush	0	0	−	110	12	Survival	3	Green				100
14	33/M	Right	Middle	Crush	0	0	−	110	12	Survival	8	Blue			+	100
15	34/M	Right	Middle	Crush	0	0	−	76	7	Survival	10	Purple	+	+		100
16	28/M	Right	Little	Crush	0	0	−	72	7	Survival						
17	17/M	Right	Middle	Crush	0	0	−	96	11	Survival						
17	17/M	Left	Middle	Crush	0	0	−	96	11	Survival						
18	22/M	Right	Middle	Crush	0	0	+	73	5	Survival	6	Blue				100
19	48/M	Right	Middle	Crush	0	0	−	76	7	Survival	8	Blue	+			100
20	32/M	Left	Middle	Crush	0	3	−	79	7	Fail						
21	37/M	Left	Index	Crush	0	0	−	83	8	Partial necrosis						
22	36/M	Left	Little	Crush	0	0	−	75	7	Fail						

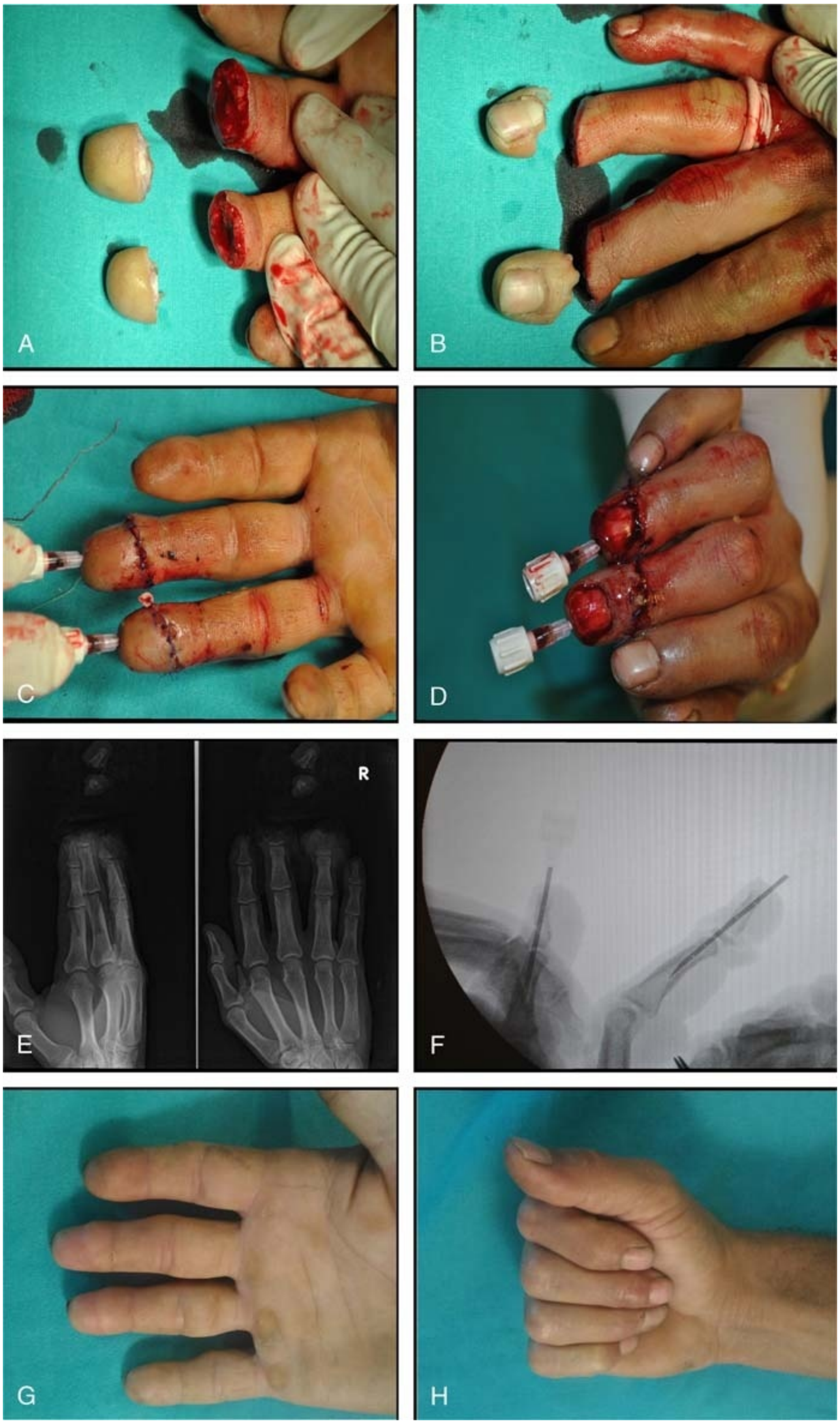

FIGURE 5. The preoperative (A, B), intraoperative (B, C), intraoperative x-ray (C, D), and postoperative first year (E, F) views of the amputated third and fourth fingers in Tamai zone 1 level. The postoperative views show good cosmetic and functional results (G, H).

The limitation of this study is that the passage of venous blood through the perforated needle and its absorption into the intramedullary system could not be demonstrated. However, the efficiency of this system is demonstrated by the fact that venous congestion developed in only 4 of the 22 cases and that recovery occurred in all of these cases after the irrigation of the needle lumen. Experimental studies

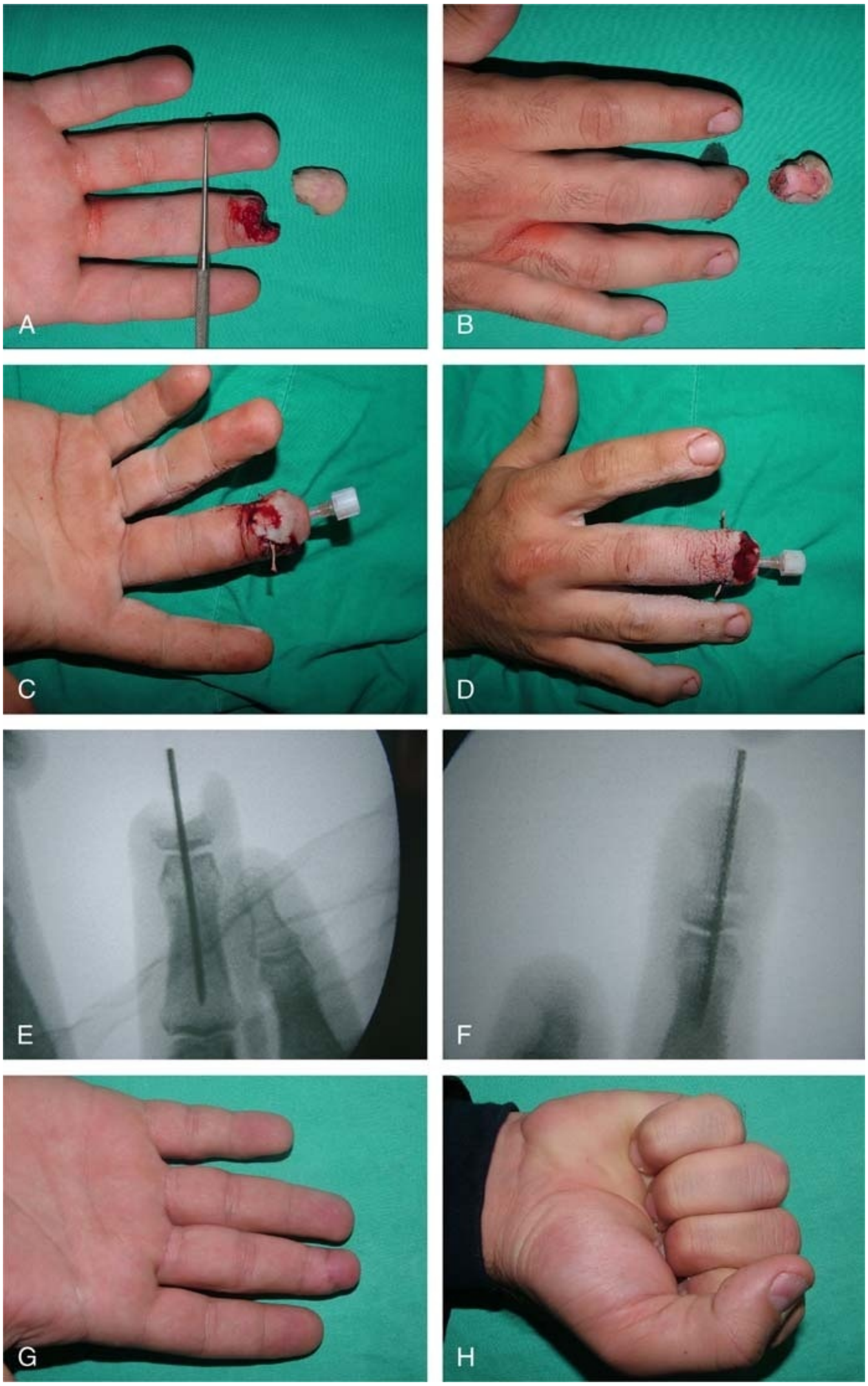

FIGURE 6. Tamai zone 1 level fingertip amputation of the third finger. The preoperative (A, B), intraoperative (C, D), intraoperative x-ray (E, F), and postoperative first year (G, H) views. The postoperative views show good cosmetic and functional results.

are planned to support the efficiency of this system, and the results will also be reported.

CONCLUSIONS

We think that the intramedullary venous drainage system we introduced is a good alternative for the venous-congestion problem in zone 1 amputations when a vein anastomosis is not possible. Zone 1 replantations can be performed safely with this technique in cases where no suitable vein has been found for repair.

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