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ORIGINAL RESEARCH



The Roles of Injury Type, Injury Level and Amputation Type in the Need for Revision Surgery after Replantation: Retrospective Clinical Outcome with 296 Finger Replantation

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ABSTRACT

Background: With the development of microsurgical techniques, the replantation survival rate has increased, but in some cases, revision surgery is required. Although there are many studies on replantation survival rate, studies on revision surgery are limited. In this study, we evaluated replantation patients requiring revision surgery in terms of amputation level, injury type, and amputation type (single-multiple).

Methods: This is a retrospective study. Two hundred fifty-six patients (296 fingers) who were operated on for total finger amputation in our hospital between 2013 and 2018 were included in the study. In the postoperative period, revision surgery was required for 24 fingers due to vascular insufficiency. Patients were evaluated in terms of amputation level, injury type, and amputation type.

Results: Two hundred sixty-four fingers were saved after primary surgery. Eight fingers failed before they could undergo revision surgery. Revision surgery was performed for 24 fingers. After revision surgery, 19 fingers were saved, and five fingers were failed. There was no significant effect of gender and age in terms of revision ($p > 0.05$). There was no statistically significant difference in injury level and injury type, but there was a statistically significant difference in terms of amputation type ($p < 0.05$).

Conclusion: Despite advanced microsurgery and experience, vascular insufficiency can be observed after replantation. Surgical re-exploration is necessary for salvage.

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Finger replantation; revision; hand surgery

Introduction

Finger replantation is a challenging and delicate procedure in microsurgery.¹ Many replantations have been carried out throughout the world over the years after the first successful finger replantation in 1968.² Surgical methods have also been developed to increase replantation survival rate.³ Although the replantation success rate is approximately 90%, revision surgery is required in some cases.⁴ The reasons for revision surgery are numerous and depend on the patient or the type of injury.

Although many publications discuss the survival rate of replantation, there are few publications on salvage revision surgery after replantation.^{5–7} Güntürk et al. reported on the correlation between revision surgery and injury type/injury level in cases where surgeons performed salvage revision surgery after a single finger replantation.⁵ However, they did not include patients with multiple amputations in their study. Berlin et al. presented their analysis of digital replantations in children; however, they did not provide any data on adult patients.⁶

In this study, we evaluated cases of salvage revision surgery in adult patients after replantation with a focus on injury type, amputation level, and single/multiple amputations.

Materials and methods

Patient characteristics and the study protocol

This is a retrospective study that was conducted in our hospital between 2013 and 2018. Approval to conduct the study was obtained from the local ethics committee of the authors' hospital (2019.11.1.01.080). All patients signed informed consent forms. This study was also conducted in accordance with the Declaration of Helsinki.

Inclusion criteria were as follows: Patients who presented with a total amputation as a result of avulsion and crush injury and whose amputation was replanted.

Exclusion criteria were as follows: Patients with total finger amputation as a result of a clean-cut (guillotine-style) injury, as well as metabolic diseases such as diabetes mellitus,

hypertension, smoking, alcohol, and vasopressor drug use. Patients with finger loss for another reason during follow-up.

The study included 296 fingers (from 256 patients) that were replanted. In the early postoperative period (up to 6th postoperative day), 24 fingers that required revision surgery due to vascular insufficiency were evaluated in terms of the type of injury, level of injury, and categorization as preoperative single or multiple finger amputation.

The primary outcome measures were the numbers of amputations undergoing revision in the postoperative period in terms of injury type, injury level, and single/multiple amputations.

The secondary outcome measures were the day on which the revision was taken and the evaluation of whether the reason for the revision was arterial or venous.

Surgical procedure

The general conditions of the patients were evaluated in the preoperative period. Amputated parts were wrapped with wet gauze. There was no direct ice contact to prevent frostbite. X-ray radiography of the injured hand and the amputated part was taken. Photographs of the amputated parts and stamps were taken for documentation. The patients were informed about the possibility of failure of the surgery, functional limitations after recovery, and the long treatment period. Prophylactic antibiotics were given to the patients before the operation. Tetanus prophylaxis was applied according to the patients' medical histories and wound contaminations. The amputated parts were prepared prior to surgery until the patients entered the operating room. All operations were performed by two highly experienced surgeons.

The type of injury (crush and avulsion) was determined according to the definitions presented by Dec et al. Crush injury is direct crushing of tissue with a heavy object. Avulsion injury is rapid cutting and rupture of the digit due to being pulled during injury.⁸ Amputation levels were determined as described by Sebastin et al. Zone 1 proximal—between the flexor digitorum profundus (FDP), zone 1 distal—distal to FDP insertion at the roof of the nail bed and FDS insertion, and zone 2—proximal to flexor digitorum superficialis (FDS) insertion⁹ (Figure 1).

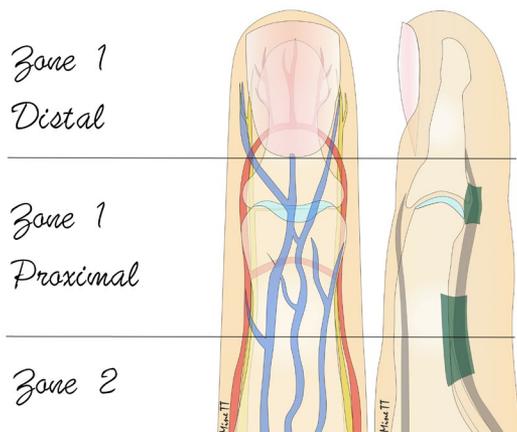


Figure 1. Amputation levels defined by Sebastin et al.⁹

In zone 1 proximal and zone 2 amputations, the stump area was debrided, and dissection was started. The order of repair was bones, tendons, arteries, veins, and nerves, in accordance with the literature.¹⁰ Bones were fixed with K wires. Flexor and extensor tendons were sutured with prolene. A Dylon was used for artery and vein repair. There were indications of vascular damage (such as a red line or a ribbon), especially in some patients with avulsion injuries. In these patients, a vein graft was taken from the volar of the forearm.

In zone 1 distal amputations, the dorsal approach technique defined by Kabakaş was used.¹¹ The amputated part and proximal stump nerve and vessels were marked. K wire was passed only through the amputated part, the volar skin of the amputated part was sutured to the proximal stump, and the dorsal part was fixed so that it could be monitored. The vessels and nerves were sutured with a Dylon. After flow was observed, the K wire was advanced proximally, and fixation was achieved. In some zone 1 distal amputations, the veins were not suitable for repair and could not be repaired. However, all patients underwent artery repair.

If there was a thumb between amputates (which occurred in multiple amputations), thumb replantation was the first step. The other fingers were ranked starting with the finger with the highest chance of survival. Unlike single finger replantations, after bone fixation and extensor tendon repair, an artery and a vein were repaired in each finger to reduce the time of ischemia, after which the nerve and flexor tendons of the fingers were repaired.

Antibiotics were given to all patients in the postoperative period. Intravenous Dextran 40 infusion (10 ml/kg/day) was administered during the operation and continued until the fourth postoperative day. When there was substantial bleeding, it was terminated before four days. Orally administered acetylsalicylic acid (300 mg/day) and orally administered pentoxifylline (3×400 mg/day) were started and continued until the third postoperative week. Enoxaparin (60 mg/day) was continued until the patients were discharged.

Postoperative hemoglobin control was performed in all patients, and blood transfusion was given to those with less than 8 ml/dl. The limb was elevated with a pillow and heated using thermal heaters. After the operation, the replanted part was evaluated in terms of color, capillary refill, turgor, and temperature.¹⁰ When poor circulation was noticed in the fingers, we determined whether the insufficiency was arterial or venous, the wound dressing had become loosened, or the skin sutures had been removed. The protocol recommended by Chen et al. was applied in cases where venous insufficiency was detected.¹² A 2 mm incision was made in the distal of the replanted finger, and 0.1 to 0.2 cc heparin (5000 IU/ml) was applied locally. If no clinical improvement was observed, revision surgery was performed for anastomosis control. Several sutures were removed from the anastomotic line, and the lumen was checked for evidence of a thrombus. Any detected thrombi were removed, and the lumen was irrigated with heparinized fluid. Vascular resection was performed for thrombi in a large vascular segment. Vein grafts taken from the forearm volar of the same extremity were if there were a gaps between the vessels.

Statistical analysis

Data analysis was performed with SPSS (IBM SPSS Statistics for Mac, Version 21.0, IBM Corp., USA). The distribution of variables and normality were checked using a Kolmogorov-Smirnov test. The mean, standard deviation, median, and interquartile range values were used for descriptive statistics. A chi-square test was used for parameters. Univariate logistic regression analyses were used to see if gender and age independently affected the revision rate. A *p*-value of less than 0.05 was considered statistically significant.

Results

Two hundred and fifty-six patients were included in the study (194 male, 62 female). The average age was (age range: 23–58 years). There were no patients excluded from the study during the study. The non-dominant hands of 69 patients and the dominant hands of 187 patients were injured (Table 1). Twenty-four of the 296 fingers that were replanted required revision surgery due to circulatory problems in the postoperative period. After replantation, 264 fingers were saved (89.1%). The number of fingers that failed without revision was 8 (2.7%) (Table 2). According to the univariate analysis, there was no significant effect of gender and age in terms of revision ($p > 0.05$) (Table 1). Average follow up time of the patients is 22.45 ± 3 (range: 11–62) months.

Primary outcomes

When evaluated in terms of level, the number of replanted fingers at the zone 1 distal level was 98, and the number of revised fingers was 8 (after revision 1 finger was failed). The number of replanted fingers at the zone 1 proximal

level was 104, and the number of revised fingers was 7 (after revision 2 fingers were failed). The number of replanted fingers at the zone 2 level was 94, and the number of revised fingers was 9 (After revision 2 fingers were failed). There was no statistically significant difference between the revision fingers in terms of injury level ($p > 0.05$) (Table 3; Figure 2).

When evaluated in terms of the type of injury, the number of fingers replanted as a result of avulsion was 112, and the number of fingers under revision was 10 (after revision 2 fingers were failed). The number of fingers replanted as a result of crushing was 184, and the number of revised fingers was 14 (after revision 3 fingers were failed). There was no statistically significant difference in the type of injury in the revised fingers ($p > 0.05$) (Table 3; Figure 3).

When evaluated in terms of single or multiple amputations, the number of fingers replanted due to single amputation was 252, and the number of fingers that required revision was 10 (After revision 2 fingers were failed). The number of fingers replanted due to multiple amputations was 44, and the number of fingers that were revised was 14 (After revision 3 fingers were failed). A statistically significant difference was found in the revised fingers in terms of single or multiple amputations ($p < 0.05$) (Table 3; Figure 4).

Secondary outcomes

When viewed from the vascular insufficiency arterial insufficiency was detected in 23 of the 24 fingers that were revised, while venous insufficiency was observed in only 1 of them.

How the cases of arterial and venous insufficiency are treated is summarized in Table 4. In addition a statistically significant difference was found in the revised fingers in

Table 1. Descriptive analysis of the patients.

	Injury type		Injury level			Amputation type		<i>p</i> value
	Avulsion (n = 76)	Crush (n = 180)	Zone 1 distal (n = 90)	Zone 1 proximal (n = 92)	Zone 2 (n = 74)	Multiple (n = 16)	Single (n = 240)	Univariate analysis
Gender	44 F 32 M	18 F 162 M	21 F 69 M	24 F 68 M	17 F 57 M	5 F 11 M	57 F 183 M	0.707
Age	42.3	46.2	38.4	47.4	42.1	41	45.3	0.85
Hand								
Dominant	34	35	23	25	21	9	60	–
Non dominant	42	145	67	67	53	7	180	

F=female; M=male.

Table 2. Descriptive characteristics of patients who were successful or failed without revision surgery after replantation.

	Successful (n = 264)		Failure without revision (n = 8)	
	Count	Row N%	Count	Row N%
Injury type				
Crush	166	62.8	4	50
Avulsion	98	37.2	4	50
Level of injury				
Zone 1 distal	87	32.9	3	37.5
Zone 1 proximal	94	35.6	3	37.5
Zone 2	83	31.4	2	25
Amputation type				
Single	239	90.5	3	37.5
Multiple	25	9.5	5	62.5

Table 3. The parameters affecting the revision and their statistical results.

	Successful after revision (n = 19)		Failure after revision (n = 5)		No. of revised fingers/No. of total replanted fingers	p value
	Count	Row N%	Count	Row N%	Ratio (row N%)	
Injury tpe						>0.05
Crush	11	57.8	3	60	14/184 (7.6%)	
Avulsion	8	42.2	2	40	10/112 (8.9%)	
Level of injury						>0.05
Zone 1 distal	8	42.1	1	20	9/98 (9.2%)	
Zone 1 proximal	5	26.3	2	40	7/104 (6.7%)	
Zone 2	6	31.6	2	40	8/94 (8.5%)	
Amputation type						<0.05*
Single	8	42.2	2	40	10/252 (3.9%)	
Multiple	11	57.8	3	60	14/44 (31.8%)	

*Statistically significant.

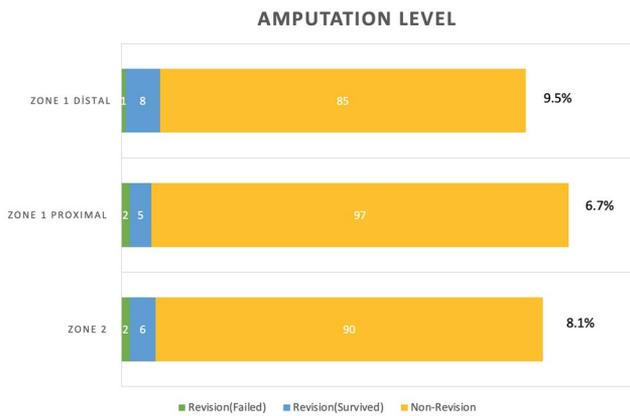


Figure 2. The graphic of amputation level results.

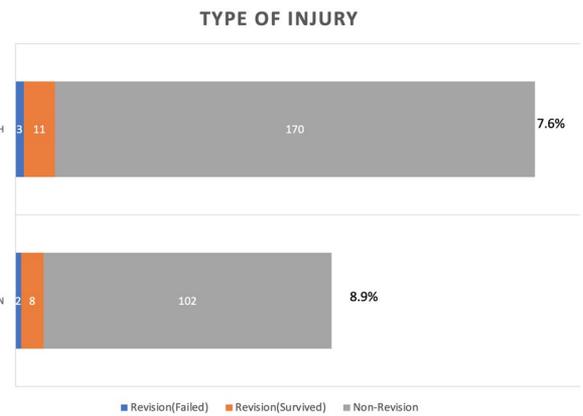


Figure 4. The graphic of type of amputation. *Statistically significant.

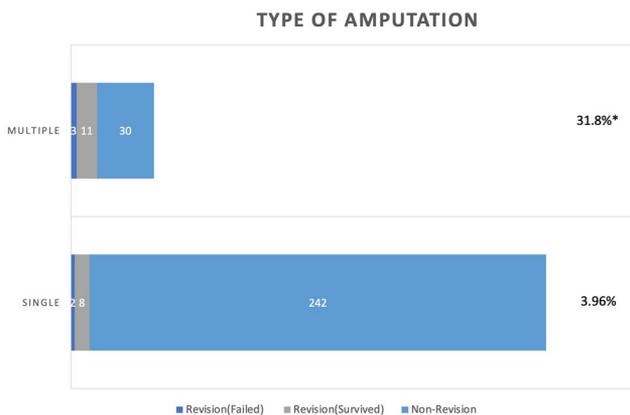


Figure 3. The graphic of type of injury results.

terms of arterial and venous insufficiency ($p < 0.05$) (Table 4; Figure 5).

In terms of the period of revision, while the rate of recovery was high in cases that were revised up to the third day after replantation (12/18), no finger that was revised after the sixth day failed to survive (0/6).

Discussion

Finger replantation was performed microsurgically for the first time by Tamai and Komatsu in 1968.² Today, with the

further development of microsurgical techniques, the salvage rate has increased to approximately 92%.¹³ However, despite the high salvage rate, there are cases requiring revision surgery due to post-replantation vascular insufficiency.^{6,7} Post-replantation vascular insufficiency may occur due to many reasons related to the patient or injury. Early detection and intervention for vascular insufficiency positively increase the possibility of digit salvage.¹⁴

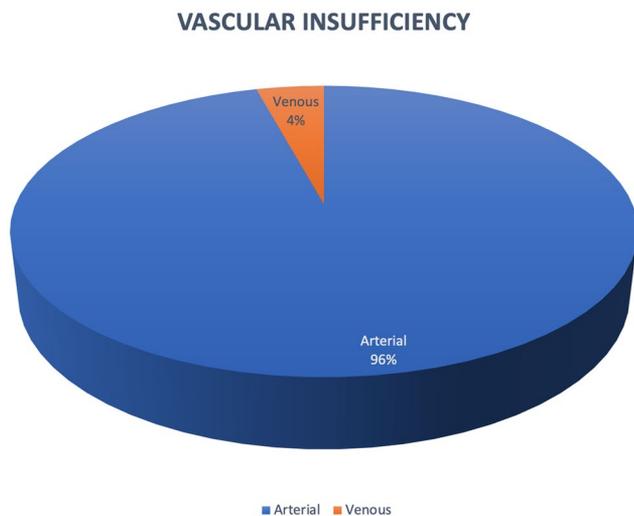
In this study, we evaluated cases requiring revision surgery after replantation in our hospital in terms of injury type, injury level, and amputation (single or multiple). Although it is stated in many publications and textbooks that multiple amputations, all thumb amputations at the level of the proximal insertion of FDS (flexor digitorum superficialis), and amputations in children are indications for operation,¹⁵ we operated on all repairable fingers in our clinical practice, regardless of the level. Intramedullary synthesis method was used for bone fixation during the operations. Thus, union has been achieved in a large number of patients.¹⁶

The success of replantation is directly related to the presence of healthy vessels at the amputation level. Vein repair is not always possible, especially in distal type amputations. Although some studies report that vein repair in distal type replantations does not make a significant contribution to finger survival, there are also publications indicating that distal replantations with vein repair have higher survival rates.^{9,17} Some surgical techniques have been suggested for salvage in cases where the vein is not repaired.

Table 4. Vascular insufficiency rates and procedures in patients with revision surgery.

	Successful after revision (n = 19)		Failure after revision (n = 5)		No. of vascular insufficiency fingers/No. of revised fingers Ratio (row N%)	p value
	Count	Row N%	Count	Row N%		
Vascular insufficiency						<0.05*
Venous	1	4.2	0	0	1/24 (4.2%)	
Arterial	18	95.8	5	100	23/24 (95.8%)	
Artery repair type					—	—
Cut, clean and reanastomosis	8	44.4	2	40		
Hematoma evacuation	1	5.6	1	20		
Vein graft	7	38.9	1	20		
Cross anastomosis	2	11.1	1	20		
Vein repair type					—	—
Cut, clean and reanastomosis	1	100	0	0		

*Statistically significant.

**Figure 5.** The pie chart of vascular insufficiency.

Medical leech therapy is recommended in addition to surgical techniques. However, medical leech therapy is not available in some centers, and patients may be incompatible with this intervention. In addition, infection as a result of leech therapy is an important disadvantage.^{12,18,19} In our clinical practice, we applied the protocol defined by Chen et al.¹² Han et al. reported the average day of venous vessel formation with external bleeding as 7.6.²⁰ This time was shortened with the protocol we used.

According to the results of Dec's study, the survival rate of distal phalanx amputations is significantly lower (2.14 times) compared to other levels.⁸ Güntürk et al. found no significant difference in terms of injury level and revision rate.⁵ Our study is correlated with work by Güntürk et al.; the probable reason for this is that we have considerable experience with distal amputations.

There are publications in the literature discussing the effect of injury type on replantation survival and revision.^{7,8,13} It is known that the progression of clean-cut injury is better than avulsion and crush injuries.⁹ Therefore,

patients with guillotine-style injuries were excluded from our study. In our study, it was found that there was no significant difference between injury types in terms of the need for revision. Our result is correlated with the studies of Breahna, Yu, and Sebastinin.^{1,8,9}

The recommended approach in multiple amputations is to start with the finger that is most likely to survive. However, the thumb is the exception; it is necessary to begin with the thumb.²¹ As mentioned earlier, the order of repair in the case of multiple amputations is different from the case of a single finger. Vascular repair was performed on all fingers to reduce ischemia time after bone fixation and extensor tendon repair. A significant difference was found between the multiple amputations and single amputations in terms of the need for revision surgery. The most important reason for this was deterioration of the surgeon's condition. We think that using two different microscopes by two senior surgeons in appropriate cases will solve this problem to a great extent. Another reason is the negative change in vascular flow after multiple amputation. These negative changes increase the need for revision surgery.

In the majority of studies in the literature, the vast majority of vascular insufficiency has been noted as venous insufficiency.^{22–26} However, arterial insufficiency was also the root cause in some studies.¹⁴ In our study, arterial insufficiency was observed more often than venous insufficiency. Our general approach was to repair veins, even in type 1 distal amputations, so we did not observe many cases of venous insufficiency. In addition, in distal cases where the vein was not repaired, the need for revision was mostly observed as arterial insufficiency, since salvage was provided with distal bleeding.

We think that the time between replantation and revision surgery affects salvage. Although Güntürk et al. reported that revision time did not affect salvage,⁵ the authors did not perform revisions after the 144th hour. In our study, we saw a significant decrease in the salvage rate in cases taken after the seventh day.

Apart from the parameters we investigated in our study, many parameters affect the need for revision or the success of replantation. It is undesirable for the amputate to be

exposed to cold ischemia before the operation. Due to the location of our hospital, the duration of cold ischemia is not exceeded in our cases. Cases exceeding the duration of cold ischemia were also not included. In addition, as previously mentioned, patients who lost their fingers for other reasons during follow-up were not included in the study. Our hospital is located close to the largest industrial zone of our country. For this reason, the number of patients admitted due to amputation is higher than in other hospitals. This situation ensures that the experience of the surgeons performing the operation increases day by day. In correlation with experience, not only proximal replantations, but also distal replantations are more successful. The high number of our patients and the low rate of revision surgery are related to the aforementioned reasons. If we had worked in a relatively less busy hospital, our results probably would not have been as successful.

The results of this study are limited. Since our study was retrospective, it was challenging to create a homogenous group because there are many variables (social, economic, ethnic) that are patient dependent.

In conclusion, despite microsurgical experience or advanced microsurgery methods, vascular insufficiency can be observed after replantation. Surgical re-exploration is necessary for salvage. Based on our data, we see that close monitoring, early diagnosis, and intervention are essential. We are of the opinion that our results will inform future studies.

Disclosure statement

No potential conflict of interest was reported by the authors.

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