Replantation and revascularization vs. amputation in injured digits

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Published online: 26 March 2013
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Abstract

Background The purpose of this study was to analyze factors associated with the decision to replant or revascularize rather than amputate an injured digit as well as factors associated with successful replantation or revascularization. **Methods** We reviewed 315 complete and subtotal amputations at or proximal to the distal interphalangeal joint in 199 adult patients treated over 10 years. Ninety-three digits were replanted (30 %), 51 were revascularized (16 %), and 171 were amputated (54 %), including 5 attempted replantations. Bivariate and multivariable analyses sought factors associated with replantation vs. amputation, revascularization vs. amputation, and success of replantation or revascularization. **Results** Factors associated with replantation rather than amputation were injury to the left hand, thumb, middle digit, and ring digit, more than one digit affected, and surgeon. Factors associated with revascularization are surgeon and shorter ischemia time. Forty-five replantations (48 %) and 41 revascularizations (80 %) were successful. Successful replantation was associated with the side of injury (left side more likely to survive), zone of injury (distal interphalangeal and interphalangeal joint more likely to survive and proximal phalanx less likely to survive), and shorter ischemia time. Success of revascularization was associated with the mechanism of injury (saw and not crush injury), multiple digits involved, and the surgeon. **Conclusions** The decision to replant, revascularize, or amputate a nonviable digit and the success of replantation and revascularization are related to both injury factors, such as

mechanism of injury, affected digit, and zone of injury, and the surgeon.

Keywords Replantation · Revascularization · Amputation · Traumatic · Success

Introduction

Generally accepted indications for replantation or revascularization are an amputation at the thumb, amputation of multiple digits, and all amputations in children [1, 6, 17]. Improvements in microvascular techniques and instruments [10, 18], patient preferences [13, 15], technical abilities, surgeon preferences, and available evidence also affect decision-making [8, 16], which remains quite variable.

Success rates of replantation and revascularization differ between institutions. Waikakul et al. report a success rate of 93 % in both complete and subtotal amputations [19], while Lindfors and Raatikainen report a success rate of 55 % for complete and 77 % for subtotal amputations [11]. Success rates may relate in part to the training and expertise of the surgeon [5] as well as the level of injury (metacarpophalangeal [MCP] and distal interphalangeal [DIP] joints vs. proximal interphalangeal [PIP] joint), mechanism of injury (blade vs. crush and avulsion), complete vs. subtotal amputation, age, sex (women have better results than men mostly due to less severe injuries), general health, smoking status, ischemia time, patient selection, and other factors [2, 5, 8, 12, 14, 17, 19]. The most common early complication after replantation and revascularization is arterial or venous thrombosis, usually within the first 2 days [9, 16]. A strong risk factor for thrombosis is smoking [3, 7]. Late complications are tendon adhesion, malunion and nonunion, neuroma, and cold intolerance [2, 15, 17].

The purposes of this study were (1) to analyze the factors that influence the decision to replant or revascularize rather

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than amputate and (2) to analyze determinants of a successful replantation or revascularization.

Materials and Methods

Study Design

Using a protocol approved by the Institutional Review Board at Massachusetts General Hospital, we retrospectively identified and reviewed 503 amputated or dysvascular digits in 345 patients treated between July 2001 and January 2011 using billing records at a single institution. Patients were included if (1) they had digit amputations from the DIP joint to the MCP joint, (2) they were 18 years of age or older, and (3) the amputation was either complete (total) or subtotal (the main vascular connections interrupted and no evidence of circulation [4]). Injuries distal of the DIP all underwent revision amputation (124 digits) and were excluded from further analysis. Sixty-four subtotal injuries were also excluded because they had perioperative evidence of circulation and were stated to be viable by the treating surgeon, leaving a cohort of 199 patients with 315 digits (Table 1).

Table 1 Overview of 199 patients with 315 fingers

Patient demographics		
Age (years)	Mean	
	Range	18 to 83
Sex	Male	184
	Female	15
Numbers of digits injured	1	182
	2	40
	3	13
	4	1
	5	2
Mechanism of injury	Blade	6
	Saw	116
	Crush	50
	Avulsion	25
	Unclear	2
Smoking	Yes	54
	No	62
	Unclear	83
Ischemia time (h)	Mean	
	Range	1.5 to 120
Total procedures/digits		
Replantation, complete amputations		93
Revascularization, incomplete nonviable amputations		51
Revision amputation, complete amputations		115
incomplete nonviable amputations		56

Definitions

The mechanisms of injury were classified into blade injuries (clean-cut sharp amputations) [4, 5], saw injuries, crush injuries [2, 4], and avulsion injuries [2, 5]. We recorded the affected side, digit (thumb, index, middle, ring, and small digits), and zone of injury (DIP joint [including the interphalangeal (IP) joint of the thumb], middle phalanx, PIP joint, proximal phalanx, and MCP joint).

The following were also recorded: age, sex, race, smoking status, date of surgery, ischemia time, type of surgery (revision amputation vs. revascularization vs. replantation), follow-up (days after surgery), success of replantation, and presence of complications. Ischemia time was defined as the time between the accident and the beginning of the operation. All digits were followed up for at least 1 week. The survival of the digits was classified into three groups: vital, partial necrosis, or total necrosis.

Demographics

The 315 traumatic amputated digits were divided into three main groups: replantation of complete amputations, revascularization of subtotal amputations, and revision amputation. Five attempted replantations failed intraoperatively and were assigned to the revision amputation group. Forty surgeons were involved in the treatment of digit amputations, but the majority of the surgeries were performed by 1 of 3 attending surgeons. The remaining 37 surgeons were analyzed together in 1 group.

Ninety-three amputations in 64 patients were replanted. Forty-two patients had only 1 digit affected, 16 patients had 2 digits, 5 patients had 3 digits, and 1 patient had 4 amputated digits. Ten of the 93 replantations (11 %) were single digits other than the thumb. Seventy-one digits had bony fixation with K-wires, 13 with a plate, and 2 with a screw. Three patients had a combination of a K-wire and a screw. Four complete amputated digits were transferred to another amputated part. Seventeen digits underwent arthrodesis: 3 DIP joints, 2 IP joints, 8 PIP joints, and 4 MCP joints. Seventy-one digits underwent direct arterial repair and 22 had a vein graft. Seventy digits had direct vein repair, 4 had a graft, and 19 digits had no vein repair. Eighty-three percent of the replantations were done by the three main surgeons. The mean follow-up was 13 days.

Fifty-one digits in 39 patients underwent revascularization. Thirty-one patients had only 1 digit affected, 6 patients had 2 digits, 1 patient had 3 digits, and 1 patient had 5 digits involved. Twelve of the 51 revascularizations (24 %) were single digits other than the thumb. Thirty digits had bony fixation with K-wires, 12 with a plate, and 4 with a screw. Two digits underwent arthrodesis: 1 thumb IP joint and 1 PIP joint. Forty-three digits had direct arterial repair and

8 had a vein graft. Direct vein repair took place in 14 digits and 37 veins were not repaired. Eighty-two percent of the revascularizations were performed by the three surgeons. The mean follow-up was 12 days.

One hundred seventy-one amputated digits in 135 patients underwent revision amputation. In 109 patients only 1 digit was involved, 18 patients had 2 injured digits, 7 had 3 injured digits, and 1 patient injured all 5 digits. Forty-four percent of the revision amputations were done by the three main surgeons. The mean follow-up was 7 days.

Statistical Analysis

In bivariate analyses, categorical explanatory variables were evaluated using the chi-square test and Fisher's exact test, and continuous explanatory variables were evaluated using unpaired *t* tests (Tables 2, 3, 4, and 5). Factors with $p < 0.10$ in the bivariate analysis were entered into multivariable analysis using binary logistic regression (Table 6).

Results

Replantation

The mean ischemia time was 5.6 h, with a median of 5 h (range, 2 to 27 h). In 20 cases, the ischemia time was not mentioned and we imputed the mean for the binary logistic regression. Forty-five replantations (48 %) survived. Forty-eight (52 %) had either partial ($n=12$) or complete ($n=36$) necrosis and were amputated. A salvage of the digit was attempted in 5 of these 48 patients with cyanosis or partial necrosis. All attempts failed and underwent revision amputation. The decision-making was based on the individual surgeon's assessment.

Revascularization

The mean ischemia time was 5.3 h, with a median of 5 h (range, 2 to 12 h). In 10 cases, the ischemia time was not mentioned and we imputed the mean for the binary logistic regression. Forty-one revascularizations (80 %) were completely vital and 10 digits (20 %) with either partial ($n=4$) or total ($n=6$) necrosis were amputated.

Revision Amputation

The mean time between the injury and the operation was 8.9 h, with a median of 6 h (range, 3 to 120 h). In 23 cases, the time was not mentioned.

Table 2 Bivariate analysis of replantation rather than revision amputation for complete amputations excluding fingertip amputations, $n=208$

	Replantation/amputation (93/115)	<i>p</i> value
Surgeon		<0.001
Surgeon A	(8/12)	0.66
Surgeon B	(8/24)	0.015
Surgeon C	(61/23)	<0.001
Others	(16/56)	<0.001
Sex		0.31
Male	(87/103)	
Female	(6/12)	
Age, mean (years)	(40/45)	0.02
Smoking		0.4
Yes	(19/28)	
No	(38/41)	
Mechanism		0.001
Blade	(6/2)	0.14
Saw	(66/61)	0.008
Crush	(13/31)	0.011
Avulsion	(5/18)	0.019
Side		<0.001
Right	(19/54)	
Left	(74/61)	
Digit		<0.001
Thumb	(23/12)	0.006
Index	(18/37)	0.037
Long	(26/17)	0.02
Ring	(21/28)	0.77
Small	(5/21)	0.005
Zone		0.058
Distal phalanx	(2/0)	0.2
DIP/IP	(8/19)	0.091
Middle phalanx	(23/34)	0.44
PIP	(9/17)	0.27
Proximal phalanx	(34/35)	0.35
MCP	(17/10)	0.041
Numbers of digits affected		0.011
One	(21/45)	
More than one	(72/70)	
Ischemia time, mean (h)	(5.6/7.7)	0.070
Follow-up, mean (months)	(13/8)	0.004

The number of affected cases are in parentheses

n number of digits

Replantation vs. Revision Amputation for Complete Amputation

In bivariate analysis, the decision to perform a replantation or revision amputation was significantly associated with the following factors: age (younger patients

Table 3 Bivariate analysis of revascularization rather than revision amputation for incomplete nonviable amputations excluding fingertip amputations, $n=107$

	Revascularization/amputation (51/56)	<i>p</i> value
Surgeon		<0.001
Surgeon A	(7/5)	0.43
Surgeon B	(10/7)	0.32
Surgeon C	(25/4)	<0.001
Others	(9/40)	<0.001
Sex		0.097
Male	(49/48)	
Female	(2/8)	
Age, mean (years)	(42/46)	0.17
Smoking		0.94
Yes	(12/16)	
No	(13/18)	
Mechanism		0.30
Blade	(0/0)	
Saw	(34/29)	
Crush	(12/19)	
Avulsion	(5/8)	
Side		0.11
Right	(16/26)	
Left	(35/30)	
Digit		0.22
Thumb	(9/3)	
Index	(10/8)	
Long	(17/25)	
Ring	(10/11)	
Small	(5/9)	
Zone		<0.001
DIP/IP	(3/10)	0.058
Middle phalanx	(11/23)	0.03
PIP	(3/11)	0.035
Proximal phalanx	(21/12)	0.027
MCP	(13/0)	<0.001
Numbers of digits affected		0.002
One	(16/34)	
More than one	(35/22)	
Ischemia time, mean (h)	(5.3/11)	0.044
Follow-up, mean (months)	(14/5)	<0.001

The number of affected cases are in parentheses

n number of digits

were more likely replanted), side (right-sided injuries were more likely amputated), number of affected digits (more than one digit affected), digit (thumb and long digits were more likely replanted, index and small digits were less likely), level of injury (MCP joint level more likely to be replanted), mechanism of injury (saw injury more likely replanted, crush and avulsion injuries more

Table 4 Bivariate analysis of factors associated with survival (viable vs. necrosis) in the replantation group, $n=93$

	Viable/necrosis (45/48)	<i>p</i> value
Surgeon		0.47
Surgeon A	(3/5)	
Surgeon B	(2/6)	
Surgeon C	(32/29)	
Others	(8/8)	
Sex		0.68
Male	(43/44)	
Female	(2/4)	
Age, mean (years)	(40/40)	0.79
Smoking		0.45
Yes	(10/9)	
No	(16/22)	
Mechanism		0.088
Blade	(5/1)	
Saw	(32/34)	
Crush	(3/10)	
Avulsion	(3/2)	
Side		0.031
Right	(5/14)	
Left	(40/34)	
Digit		0.088
Thumb	(14/9)	
Index	(4/14)	
Long	(12/14)	
Ring	(13/8)	
Small	(2/3)	
Zone		0.023
Distal phalanx	(1/1)	1.0
DIP/IP	(7/1)	0.027
Middle phalanx	(12/11)	0.68
PIP	(7/2)	0.084
Proximal phalanx	(10/24)	0.005
MCP	(8/9)	0.9
Numbers of digits affected		0.94
One	(10/11)	
More than one	(35/37)	
Ischemia time, mean (h)	(4.6/6.3)	0.015
Follow-up, mean (months)	(12/13)	0.75

The number of affected cases are in parentheses

n number of digits

likely amputated), and the surgeon performing the procedure (surgeon C more likely replanted, surgeon B and other surgeons more likely amputated) (Table 2). In multivariable analysis, significant independent predictors for replantation rather than revision amputation are injury to the left hand, thumb, middle digit, and ring digit, more than one digit affected, and surgeon C (Table 6).

Table 5 Bivariate analysis of factors associated with survival (viable vs. necrosis) in the revascularization group, $n=51$

	Viable/necrosis (41/10)	<i>p</i> value
Surgeon		0.038
Surgeon A	(5/2)	0.61
Surgeon B	(7/3)	0.39
Surgeon C	(24/1)	0.011
Others	(5/4)	0.061
Sex		0.36
Male	(40/9)	
Female	(1/1)	
Age, mean (years)	(44/35)	0.075
Smoking		0.59
Yes	(10/2)	
No	(12/1)	
Mechanism		0.023
Blade	(0/0)	
Saw	(31/3)	0.01
Crush	(7/5)	0.042
Avulsion	(3/2)	0.25
Side		0.25
Right	(11/5)	
Left	(30/5)	
Digit		0.99
Thumb	(7/2)	
Index	(8/2)	
Long	(14/3)	
Ring	(8/2)	
Small	(4/1)	
Zone		0.68
DIP/IP	(2/1)	
Middle phalanx	(8/3)	
PIP	(2/1)	
Proximal phalanx	(17/4)	
MCP	(12/1)	
Numbers of digits affected		0.054
One	(10/6)	
More than one	(31/4)	
Ischemia time, mean (h)	(5/5)	0.56
Follow-up, mean (months)	(14/12)	0.77

The number of affected cases are in parentheses
 n number of digits

Revascularization vs. Revision Amputation in Subtotal Amputation

The decision to perform a revascularization or revision amputation was highly dependent of the following factors in bivariate analysis: numbers of affected digits, zone of injury (middle phalanx and PIP joint were more likely amputated, proximal phalanx and MCP joint were more likely revascularized), ischemia time, and surgeon (surgeon

Table 6 Predictors

	<i>B</i> value	Sig.	Odds ratio	95 % CI		<i>R</i> ²
				Lower	Upper	
Predictors of replantation vs. revision amputation						0.36–0.48
Thumb	3.2	<0.001	24	5.1	117	
Middle finger	2.5	<0.001	12	3.0	50	
Surgeon C	2.3	<0.001	10	4.0	24	
Ring finger	1.5	0.027	4.6	1.2	18	
Side (left)	1.4	<0.001	4.2	1.9	9.2	
More than one digit affected	1.0	0.047	2.6	1.0	6.6	
Predictors of revascularization vs. revision amputation						0.48–0.65
Surgeon C	2.7	0.001	15	3.1	71	
Ischemia time	−0.5	0.001	0.60	0.45	0.82	
Predictor for failure of replantation						0.21–0.29
Ischemia time	0.44	0.013	1.6	1.1	2.2	
Predictor for failure of revascularization						0.16–0.25
One digit affected	1.8	0.027	5.8	1.2	28	

C revascularized more often than other surgeons) (Table 3). Only surgeon C and shorter ischemia time were retained in the best multivariable model (Table 6).

Success of Replantation

Success of replantation was significantly correlated with the side of injury (left side more likely to survive), zone of injury (DIP and IP joints more likely to survive, and proximal phalanx less likely), and shorter ischemia time in bivariate analysis, but only shorter ischemia time was retained in the best multivariable model (Tables 4 and 6).

Success of Revascularization

Success of revascularization was significantly correlated with the mechanism of injury (saw injury and not crush injury), multiple digit involvement, and surgeon (surgeon C) in bivariate analysis, but only multiple digit involvement was retained in the best multivariable model (Tables 5 and 6).

Discussion

One hundred forty-four of 315 digits (46 %) were replanted or revascularized, including 22 single-digit non-thumb injuries (15 %) and 35 crush or avulsion injuries (24 %). The decision to amputate rather than to repair was not only related to digit, number of digits involved, and side, but also to the treating surgeon. Survival of the digit was determined by ischemia time

(replantation, 48 % overall survival) and number of digits involved (revascularization, 80 % overall survival).

These findings should be interpreted in light of several shortcomings. First, due to the fact that this was a retrospective study, there was often limited or absent information, such as smoking and ischemia time, requiring the use of mean imputation. While mean imputation of ischemia time in nearly 20 % of the patients may be questionable, we also ran the analysis without imputation; mean imputation of ischemia time did not affect the overall results in our study. Second, while the diagnosis of a complete amputation is clear, the diagnosis of a subtotal amputation is less clear because fingers can be viable even when both digital arteries are injured. We speculate that some of the between-surgeon differences in amputations rather than repair related to differences in the subjective aspects of assessing the viability of a subtotal amputation. Third, given the number of different factors in decision-making, we can only speculate regarding the interpretation of some of our findings. Lastly, no information was available about the desires of the patients and the influence of their occupation.

In our opinion, the findings regarding decision-making reflect differences in surgeon practice, with surgeon C more likely to replant a single amputated or injured digit, more likely to proceed with replantation or revascularization for crushed or avulsed injuries, and more likely to diagnose non-viability and proceed with artery repair when both arteries were definitely or possibly injured (e.g., thrombosed). This is based on our knowledge of each other's practice styles rather than the data, which can only tell us that surgeon C was more likely to replant or revascularize than the other surgeons. Otherwise, our findings are consistent with prior literature in that thumbs, middle digits, and multiple digits were more likely to be replanted and that ischemia time was also a factor [5, 15–17]. Many other factors influence the decision process and the outcome. Patient factors such as occupation and desires, education or experience level of the surgeons, and teaching status of the procedure merit further evaluation. However, these data were not collected in this study.

More right-handed injuries underwent revision amputation rather than replantation, perhaps because dominant hands were more likely to be crushed than injured by a tool or perhaps because, in dominant hands, function takes priority over esthetics, so single-finger replantations were less appealing [5, 10, 20].

Given that this study identified a strong influence of the treating surgeon on the decision to replant or revascularize complete or subtotal amputations of the finger, future studies should address the relative influence of patient

preferences and surgeon preferences on decision-making and how these relate to symptoms, disability, and satisfaction more than 1 year after injury. An improved understanding the factors that affect decision-making and success (in the many ways that success can be defined) in the management of severely injured digits might result in guidelines that are useful to surgeons and patients facing these difficult and time-sensitive decisions. Ideally, these guidelines might be clear enough to use with electronic images and direct communication prior to transfer, which sometimes involves costly and stressful long-distance transport by air or land.

Conflict of Interests All named authors hereby declare that they have no conflicts of interest to disclose related to this study.

Human Subjects Approval The authors adhere to the ethical standards described by the Committee on Publication Ethics and the International Committee of Medical Journal Editors. The study was completed under an IRB-approved protocol.

Informed Consent Informed consent was waived by the IRB for this retrospective study.

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