Free Vascularized Medial Femoral Condyle Structural Flaps for Septic Terminal Digital Bone Loss

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Abstract A unique clinical problem exists when the majority of distal bone stock in a digit is destroyed by osteomyelitis, leaving a residual soft tissue envelope with tenuous, random perfusion surrounding a nidus of scar tissue. Pulp pinch is lost in the absence of bony support, and limited options exist. Apart from toe transfer or revision amputation with shortening, non-vascularized bone grafting inside the residual soft tissue envelope risks graft resorption and reactivation of infection. The purpose of this investigation was to evaluate the clinical outcomes of free vascularized medial femoral condyle structural bone flaps to restore lost pulp pinch in such cases. Nine patients (8 males, 1 female) with a mean age of 43 years sustained extensive terminal bone loss near digital tips following osteomyelitis. The mean length of bone defect was 28 mm (± 8.4). The patients were reconstructed at a mean of 12 weeks from initial trauma/infection, having undergone a mean of two prior surgeries. A structural block of vascularized bone from the medial femoral condyle replaced the missing bone at the digital tip defect, temporarily fixed with K-wires. The bone flap was encased by the residual soft tissue envelope after removing scar tissue from the prior trauma and infection. All bone flaps incorporated fully, restoring pulp pinch function to the respective digits with a mean time to union of 8.6 (± 2.1) weeks; range 6–11 weeks. With few alternative solutions able to address this unique and difficult problem, the structural block of vascularized bone proved able to resist resorption, nonunion, and reactivation of infection; the problems normally encountered under this scenario.

Keywords Bone · Medial · Femoral · Condyle · Flap

Introduction

A unique clinical problem exists when a patient sustains open fracture trauma to the digital tip, fails to receive timely medical intervention, and then develops acute osteomyelitis that destroys the bone substance of the distal digit. Even rarer is survival of the soft tissue envelope that previously encased the now missing bone, replaced by scar tissue. The residual soft tissue envelope is poorly perfused by random blood supply alone; the terminal branches of the radial and ulnar proper digital arteries long since destroyed by either the original trauma or by septic thrombosis. Such patients have lost all digital pulp pinch function, lacking a skeletal framework. Options at this point are limited.

- Revision amputation to the level of existing skeletal structure.
- Excise the existing distal soft tissues and replace everything with a free toe transfer.
- Non-vascularized bone grafting inside the residual soft tissue envelope.
- Vascularized bone grafting inside the residual soft tissue envelope.

When a substantial amount of bone is missing, the revision amputation level is too short for digital pulp pinch function [1, 2]. Free vascularized toe transfer is an excellent procedure for single digits amputated distal to a mobile PIP joint, but in this scenario would be more than is necessary since the only missing tissue is bone [3–8]. Non-vascularized bone placed as a terminal rather than intercalary graft at the digital tip faces the problems of graft resorption and nonunion. Non-vascularized

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bone placed in a bed of prior osteomyelitis may reactivate infection. The exact probabilities of these adverse events using non-vascularized bone are not well defined in the existing literature, and the stated expectations of risk come from the collective experiences of surgeons addressing these rare cases.

The purpose of this study was to examine whether or not the application of a vascularized free bone flap from the medial femoral condyle (MFC) to the terminal position in the digit could solve the aforementioned clinical scenario. The hypothesis of the study is that, by virtue of direct vascularization, the structural bone flap would successfully resist resorption, unite, and avoid reactivation of infection. The additional challenge anticipated was the ability to inset the flap to the recipient site without inducing necrosis of the surrounding, poorly perfused soft tissue envelope.

Patients and Methods

The study is a prospective cohort series of consecutive patients sharing the same pre-operative indications. Inclusion criteria were single digit sites of previous open fracture of the distal phalanx - DIP/IP joint that, from lack of prompt debridement, became acutely infected with osteomyelitis, destroying most or all of the terminal bone substance, and in some cases the head of the phalanx on the proximal side of joint (Fig. 1). Patients were offered each of the alternatives listed above (including simple revision amputation) such that inclusion criteria included self-selection by the patients of the MFC reconstruction. Self-selection was particularly relevant for the three patients, with the largest defects in the series, who would have undergone thumb revision amputation through the proximal phalanx - more proximal than the level of the interphalangeal joint that is considered to represent an acceptable functional level

Fig. 1 Final healing of flap bridging middle phalanx to residual tuft of distal phalanx

Fig. 2 Following initial osteomyelitis of distal phalanx and proximal phalanx, prior to intra-operative additional bone removal of friable margins to enlarge defect at time of flap transfer

(Fig. 2). There were no patients who met the inclusion criteria and desired the procedure, but were then excluded. Exclusion criteria were ongoing-unresolved infection, cardiovascular comorbidity incompatible with reconstructive microsurgery, and patients unable to comply with the post-operative protections required for months of healing.

Nine consecutive patients (8 males, 1 female) with a mean age of 43 years (range 22–58 years) met these criteria. Full demographics of the patients appear in Table 1. The mean

Table 1 Patient demographics and results

Age	25	53	54	53	22	57	58	28	38
Sex	F	M	M	M	M	M	M	M	M
Digit	ring	thumb	thumb	long	long	index	thumb	ring	long
Length of defect (mm)	16	30	45	27	23	22	36	26	28
Number of prior surgeries	1	2	5	1	2	3	2	1	2
Time since initial trauma (weeks)	6	12	15	17	17	6	22	6	6
Time to achieve union (weeks)	6	10	10	6	11	10	11	6	8

length of bone defect was 28 mm (± 8.4) (range 16–45 mm). The patients were reconstructed at a mean of 12 weeks from initial trauma/infection, having undergone a mean of two prior surgeries. Part of the 12 week interval leading up to performance of the free vascularized bone flap surgery was the post-debridement course of intravenous antibiotics necessary to resolve the osteomyelitis and a subsequent observation period to confirm clinical resolution. Resolution of infection was judged clinically based on serial physical examinations of the digit correlated with radiographs of the residual bone margin, no laboratory tests were used. Another part of the 12 week interval was a clinical assessment by physical examination of the vascular stability of the soft tissue envelope surrounding the intended recipient site for the flap.

The only statistical methods employed in the study involved computation of means and standard deviations. The study does not compare outcome variables between two or more groups, obviating the need for more advanced statistical calculations.

Surgical Technique

The patients were operated supine under general anesthesia with tourniquets proximal to the surgical sites on both the

recipient upper extremity and ipsilateral donor lower extremity. The recipient site was prepared through a mid-axial incision on the digit, either radial or ulnar. Mid-axial incisions run in the neutral tension lines of the digit, avoiding a surgically induced PIP contracture post-operatively (Fig. 3). Selecting the side for approach was determined on an individual case by case basis, calculated to optimize overall clinical outcome. The variables contributing to this analysis included:

- Which digital artery constituted a better donor vessel for the flap
- Which digital artery best contributed to perfusion of the distal digit
- The quality of the residual soft tissue envelope differential between the two sides
- The geometric orientation of the bone defect recipient site
- The location of typical pulp pinch application to that specific digit

The bone defect was approached dorsal to the remaining branches of the proper digital nerve. In addition to protecting

Fig. 3 Use of a mid-axial approach prevents induction of a PIP joint scar contracture, extension (A) or flexion (B)

Fig. 4 K-wire fixation of intercalary flap with cancellous extensions of main segment inset to medullary canals of proximal phalanx and distal phalanx after additional bony debridement

both digital nerves, a minimum 3 mm thickness to the soft tissue envelope was maintained to preserve the random perfusion in the dermal plexus. The scar tissue filling the bony defect was completely removed. Irregular and unperfused bone margins were further resected, increasing the size of the bone defect. Exact dimensions of the bone defect were measured with calipers. Distance from the recipient site to vascular anastomosis was measured to determine pedicle

length (4.5 cm to 7.5 cm). Fingers were operated using a short pedicle technique with anastomoses performed to the proper digital artery and dorsal digital vein through the mid-axial approach at the level of the proximal phalanx, which provides a good vessel diameter match of just less than 1 mm (0.2 mm tying platform forceps utilized). Thumbs were operated with an arterial anastomosis to the dorsal carpal arch branch of the radial artery, which provides a good vessel diameter match using an end-to-end anastomosis. For both finger and thumb cases, the distance from recipient bone defect to vascular anastomosis was easily accommodated by either the descending genicular or superior medial genicular artery. No pre-operative vascular imaging studies were employed. The short pedicle technique also permitted a shorter, 10 cm, harvest incision on the medial distal femur. A structural block of medial femoral condyle was harvested from the distal posterior quadrant where bone perforators are the most plentiful. When viewing the MFC, two vessels are identified, a longitudinal posterior artery and an oblique anterior artery. It is the longitudinal posterior branch that serves the distal posterior quadrant with the highest concentration of bone perforators. By harvesting the flap from a distal position, not only does the surgeon ensure the best perfusion of a small sized flap, but also increases pedicle length. Once the proximal margin of the flap has been determined, the surgeon then subperiosteally dissects the vessels from the remainder of the medial femoral condyle surface and can gain as much as 5 cm pedicle length in doing so. Even the shorter superior medial genicular artery donor (present in 100 % of cases) has a pedicle length of 5 cm from the proximal margin of the medial femoral condyle. When combined with the subperiosteal dissection, this yields as much as 10 cm of pedicle length, well more than necessary for either finger or thumb cases. Seven flaps were perfused

Fig. 5 K-wire fixation of intercalary flap with cancellous extensions of main segment inset to middle phalanx and distal phalanx after additional bony debridement

Fig. 6 With sufficient bony infrastructure, firm pulp pinch can be applied through the distal digit

from the descending genicular artery, two from the superior medial genicular artery. The MFC bone flap was intentionally harvested 5 mm larger than the measured dimensions (28 mm) of the recipient defect and custom shaped with a rongeur during the inseting process. Once size and shape were optimized to fit the defect, the flap was temporarily fixed in place with K-wires (Fig. 4). The vascular anastomoses were performed and the mid-axial incision closed directly over the flap and the pedicle. Finger anastomoses to artery and vein were both end-to-end, with the respective vessels ligated sufficiently distal to bring them into the mid-axial incision and the microscope's field of view to perform the anastomosis. Pedicle compression was prevented by initial resection of scar tissue (following infection, trauma, prior surgery) to create the necessary volume defect where the pedicle was planned in transit between bone defect and anastomosis. Once bridging trabeculae were demonstrated radiographically on all views, the bone

flap was judged united and the K-wires removed (Fig. 5). Patients then initiated pulp pinch loading to the digit and an overall hand strengthening program under the supervision of therapists (Fig. 6). Determination that pulp pinch function had been restored to the digit was assessed by the patients themselves responding to the question of whether or not they were able to effectively pinch using the reconstructed digit to the degree that they reincorporated that digit into normal patterns of hand usage on a daily basis. The study assessed volitional reincorporation of the affected digit into normal patterns of functional pulp pinch; the study did not assess pinch strength as a quantitative outcome variable.

Results

All bone flaps incorporated fully, restoring pulp pinch function to the respective digits with a mean time to union of 8.6 ($\pm$ 2.1) weeks (range 6–11 weeks). Healing times for each case are provided in Table 1. There were no cases demonstrating partial or complete graft resorption. There were no cases of reactivation of infection. There were no cases of wound breakdown or necrosis of the surrounding soft tissue envelope.

Discussion

The unique clinical situation presented here so rare that there is an absence of prior literature directly addressing this problem by any method. As such, there is no standard of treatment to serve as comparison. Although a research cohort of nine patients would (for most clinical conditions) be considered quite small, it is actually a large number of patients to share this rare, previously

Fig. 7 Following initial osteomyelitis of distal phalanx and middle phalanx, prior to intra-operative additional bone removal of friable margins to enlarge defect at time of flap transfer

Fig. 8 Final healing of intercalary flap into medullary canals of proximal phalanx and distal phalanx

unpublished clinical scenario. This study is limited in scope, confined to addressing the original study hypothesis. The primary purpose of the investigation was to learn whether or not the bone flaps would resorb, unite, or become infected. The secondary purpose was to learn whether or not the already heavily damaged digit could withstand the reconstructive procedure without suffering distal necrosis. Although a small and simple series, the study does answer these questions. Perhaps the greatest weakness of the study is simply that we do not know

exactly what would have happened if these patients had been reconstructed with non-vascularized, terminally placed bone grafts. The rarity of the problem does not lend itself well to a randomized controlled trial.

The decision to use a vascularized bone flap for this clinical presentation was based on fundamental principles of reconstructive surgery. There is not a good pedicle flap option for terminal digital bone reconstruction, necessitating a free flap [9]. The choice of the MFC to supply the free vascularized bone flap was based on past experience using this flap in various distal upper extremity sites. This flap was originally described as a corticoperiosteal flap, primarily for solving recalcitrant nonunions in long bones [10–16]. Over time, an increasing number of applications in the more distal upper extremity have proven the extreme versatility of this flap [17–26]. In addition to excellent direct bony perfusion by the source vessels, the MFC flap can be customized to very small sizes without compromising that perfusion (Fig. 7) [27–29]. Primarily composed of cancellous bone with a thin cortical shell (as opposed to many of the other free vascularized bone flaps available) the MFC flap heals quite readily (Fig. 8). Although, this same attribute of cancellous composition does limit the integrity of fixation when used as a structural block, as opposed to its corticoperiosteal form. Indeed, the most difficult aspect of the cases in this series was achieving proper skeletal fixation of the flap to the recipient site as the recipient bone was also compromised in quality having been infected and deprived of force application for 3 months (Fig. 9). Despite these difficulties, no fixation was lost; the flaps all ended up healing well, and demonstrated increasing density on serial radiographs over time. For other recipient locations, the MFC flap can be harvested with a skin paddle. Obviously, such a reconstruction for a digital tip would be wholly inappropriate as the bulky and bulbous non-glabrous skin island lacks any adherence to the

Fig. 9 (A) Bone loss near thumb tip prior to final debridement; (B) MFC free bone flap inset with wire fixation

underlying bone and would preclude any meaningful pulp pinch function, thus obviating the entire purpose of the reconstruction in the first place.

The other critical issue to be considered by anyone pursuing this type of reconstruction is preservation of perfusion to the distal soft tissue envelope. In the time period immediately following management of osteomyelitis, the soft tissue envelope is in its most tenuous state of perfusion. Unlike other regions of the body, the use of such techniques as antibiotic laden cement spacers is both unnecessary and extremely dangerous. The soft tissue envelope at the digital tip does not collapse or contract because it is held out to shape by the three dimensional structure of the dermis. The vacancy is merely filled by post-infectious scar. Placement of a cement spacer with the goal of providing a distention pressure on the surrounding envelope runs a high risk of compromising the delicate, random perfusion and driving the tip on to full thickness necrosis and amputation. Placement of the bulk of the flap at the time of reconstruction also runs the same risk and constitutes one of the reasons for waiting to pursue the reconstruction until the soft tissue envelope appears to have optimally stabilized its vascular status.

Conclusion

When digital pulp pinch function has been lost through traumatic/septic destruction of distal bone stock, function can be restored with a structural MFC free bone flap in a terminal position. The MFC flap successfully resists resorption, unites, and avoids reactivation of infection. The small customizable flap can be inset without further compromising the surrounding soft tissue envelope.

Compliance with Ethical Standards

Conflicts of Interest Mark Henry MD declares that he has no conflict of interest.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments. This article does not contain any studies with animals performed by any of the authors.

Informed Consent Informed consent was obtained from all individual participants included in the study.

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