ORIGINAL ARTICLE

Bone grafting combined with a spiral flap technique for the reconstruction of fingertip amputations

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ABSTRACT

BACKGROUND: Various reconstructive options exist for distal finger and pulp defects, including grafting and local or distant flaps. In addition to reconstructing the normal anatomical structure, preserving the sensory function of the finger is crucial. This study presents the results of using bone grafting combined with a spiral flap (BGcSF) technique for reconstructing pulp defects accompanied by bone loss.

METHODS: Twenty-three patients with fingertip defects were treated using the BGcSF technique. Flap sensitivity was assessed using the Semmes-Weinstein monofilament (SWM) and static two-point discrimination (2PD) tests at six months postoperatively. Cold intolerance of the affected fingers was evaluated using the Cold Intolerance Severity Score (CISS) questionnaire at one year postoperatively. Patient satisfaction was assessed using the Michigan Hand Outcomes Questionnaire (MHQ). Range of motion (ROM) for the proximal and distal interphalangeal joints was measured with a goniometer at one year postoperatively.

RESULTS: Distal flap necrosis, affecting 10-15% of the flap area, was observed in one patient. No other complications were noted. The mean static two-point discrimination value at six months postoperatively was 5.6 mm, and the mean SWM score was 3.56. The mean CISS score at one year postoperatively was 18.8. The mean active ROM angle for the proximal interphalangeal joint was 106.7 degrees, and for the distal interphalangeal joint, it was 65.4 degrees. The mean MHQ score at one year postoperatively was 18.5.

CONCLUSION: The BGcSF technique provides soft tissue with a texture similar to that of the fingertips and supports effective sensory repair. It can be considered a viable option for fingertip reconstruction in cases where replantation is not feasible.

Keywords: Amputation; bone graft; fingertip; reconstruction; spiral flap.

INTRODUCTION

Fingertip and pulp injuries are the most common types of upper extremity injuries.[1] Particularly, the cosmetic appearance of fingertip injuries without distal interphalangeal joint involvement is as crucial as functional integrity, and efforts should be directed towards achieving acceptable outcomes.[2] Replantation is the preferred method for fingertip amputations, as with other limb amputations.[2] However, when microsurgical replantation is not feasible, numerous techniques have been developed for functional and cosmetic restoration.[3] These include unilateral, bilateral, or volar V-Y advancement flaps for small defects, and thenar, hypothenar, and cross-finger flaps for larger defects when simpler flaps are insufficient.[4-6] As subsequent options, reversed or normograde neurovascular island flaps and local perforator flaps may be considered.[7,8] For the most complex cases, free venous flaps, free pulp flaps, and trimmed toe tip methods are employed, requiring advanced microsurgical skills.[9-11]

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The choice of repair technique must consider the size and type of the defect, the status of the amputated part, the patient's medical condition and expectations, and the surgeon's preference. Fingertip reconstruction continues to be an area ripe for the exploration of various methods aimed at improving outcomes.

In this study, we present the outcomes of using bone grafting combined with a spiral flap technique for the reconstruction of pulp defects accompanied by bone loss.

MATERIALS AND METHODS

The study was approved by the ethics committee under the number 2023/84-08. Between 2016 and 2022, 23 patients (17 male, 6 female) with fingertip amputations or finger pulp defects were treated using the bone grafting combined with a spiral flap technique (Fig. 1). The average age of the patients was 21 years, ranging from 6 to 40 years. Patients were selected based on the following criteria:

1. Injury to a finger other than the thumb.
2. Absence of injury at the flap donor site.
3. No digital artery injuries.

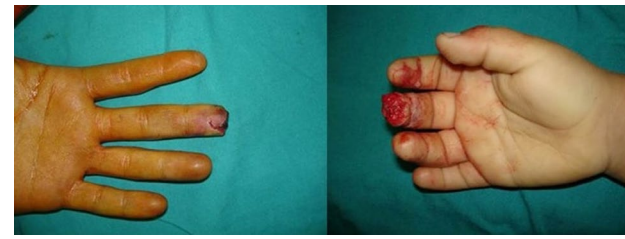

Figure 1. Two patients exhibiting Type 3-4 pulp loss.

4. No comorbid injuries that would prevent repair.
5. Availability of amputated parts suitable for use as bone grafts.

Of the injuries treated, 15 involved right hand digits and 8 involved left hand digits. The smallest defect size was 1.3x1.2 cm, and the largest was 3.1x1.5 cm (Table 1). The mean follow-up period was 32 months, ranging from 14 to 66 months. Follow-up assessments were conducted at two weeks, four weeks, six weeks, three months, six months, and one year postoperatively. Flap sensitivity was evaluated using Semmes-Weinstein monofilament and static two-point discrimination (2PD) tests at six months postoperatively. Cold intolerance of damaged fingers was evaluated using the Cold Intolerance Severity Score questionnaire at one year postoperatively.

Table 1. Demographic and surgical data of patients

Case	Age/Sex	Injured Side	Injured Finger	Defect Size cmxcm	Flap Size cmxcm	Donor Site
1	6/ M	Right	Middle	1.9x1.2	2.5x1.5	Radial
2	17/F	Right	Ring	1.4x1.3	2.0x1.5	Ulnar
3	21/M	Right	Ring	1.6x1.4	2.0x1.5	Ulnar
4	23/M	Right	Middle	2.1x1.6	2.5x2.0	Radial
5	44/M	Left	Index	1.5x1.2	2.5x1.5	Ulnar
6	15/M	Left	Ring	2.7x1.7	3.0x2.0	Radial
7	22/F	Right	Middle	3.1x1.5	4.0x2.0	Ulnar
8	19/F	Left	Index	2.2x1.2	3.0x1.5	Ulnar
9	35/M	Left	Middle	1.8x1.4	2.5x1.5	Radial
10	37/M	Left	Ring	1.3x1.2	2.5x1.5	Ulnar
11	40/F	Right	Ring	2.6x1.5	3.0x2.0	Radial
12	18/M	Right	Index	2.0x1.4	2.5x1.5	Radial
13	17/F	Left	Middle	1.5x1.2	2.5x1.5	Radial
14	14/M	Left	Middle	1.7x1.3	2.5x1.5	Radial
15	22/M	Right	Ring	1.8x1.5	2.5x1.5	Ulnar
16	32/M	Left	Index	2.0x1.6	2.5x2.0	Radial
17	16/F	Right	Index	2.0x1.5	2.5x1.5	Radial
18	21/M	Right	Middle	1.6x1.4	2.0x1.5	Ulnar
19	16/M	Right	Ring	1.5x1.3	2.0x1.5	Radial
20	15/M	Right	Index	3.0x1.6	4.0x2.0	Radial
22	17/M	Right	Middle	2.7x1.5	3.5x2.0	Ulnar
23	18/M	Right	Ring	2.0x1.4	2.5x1.5	Ulnar

Table 2. Postoperative evaluation of reconstructed fingers

Case	Injured Finger	Static 2PD, mm	SWM	MHQ Scores		ROM PIP Joint	ROM DIP Joint	CISS
				Function	Cosmetic			
1	Middle	5	3.22	5	4	110	70	16
2	Ring	6	3.61	5	5	105	65	18
3	Ring	5	3.61	4	5	95	60	22
4	Middle	6	3.84	5	4	110	70	20
5	Index	5	3.61	5	4	100	60	18
6	Ring	6	3.84	4	4	110	70	24
7	Middle	5	3.22	5	5	100	60	20
8	Index	6	3.22	4	5	105	65	24
9	Middle	6	3.61	4	4	110	70	20
10	Ring	7	4.17	5	5	110	70	22
11	Ring	7	3.84	5	5	115	70	24
12	Index	6	3.61	5	5	110	65	16
13	Middle	5	3.22	5	5	110	65	18
14	Middle	5	3.22	5	5	105	60	16
15	Ring	6	3.61	5	5	105	60	22
16	Index	7	4.08	5	5	100	65	18
17	Index	5	3.22	4	4	100	60	18
18	Middle	5	3.22	5	5	115	70	18
19	Ring	5	3.61	5	4	110	70	16
20	Index	5	3.61	5	4	105	65	18
21	Middle	6	3.84	5	5	110	70	16
22	Ring	5	3.22	5	5	100	60	8
23	Middle	6	3.84	5	4	115	65	16

2PD: Two-Point Discrimination; CISS: Cold Intolerance Severity Score; DIP: Distal Interphalangeal Joint; PIP: Proximal Interphalangeal Joint; ROM: Range of Motion; SWM: Semmes-Weinstein Monofilament Test.

Patient satisfaction was measured using the Michigan Hand Outcomes Questionnaire. Additionally, the active range of motion (ROM) of the proximal and distal interphalangeal joints was measured with a goniometer at one year postoperatively.

Surgical Technique

All procedures were performed under axillary block or general anesthesia with a tourniquet. The injured fingers were debrided before planning the flap, which was designed to be slightly larger than the defect area. Bone fragments were prepared for grafting from amputated parts that could not be replanted. The flap did not exceed the width of the defect. Two oblique incisions were made on the dorsum and volar aspects of the mid phalanx of the injured finger, extending proximally and converging on the dorsum of the middle phalanx. The neurovascular bundle on the side of the incisions was protected (Fig. 2a,b). A zig-zag incision was made proximal to the protected neurovascular bundle, exposing the digital artery and nerve, and positioning the bundle at the midline of the

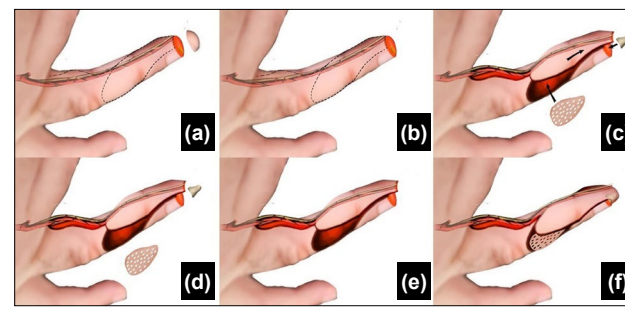

Figure 2. (a,b,c) Two oblique incisions were made on both the dorsum and volar aspects of the injured finger, converging on the dorsum. The neurovascular bundle was protected where the incisions were made. A zig-zag incision was then performed proximal to the protected neurovascular bundle, exposing the digital artery and nerve. **(d,e,f)**: Bone fragments were prepared for bone grafting. The flap was elevated on the extensor tenosynovium from the dorsum to the volar side along the flexor digitorum profundus tenosynovium. The defect was completely closed by transposing the flap from the dorsal to the volar side. A full-thickness skin graft was applied to the donor area.

Figure 3. Flap raising procedure.

Figure 4. Flap adaptation. The defect at the flap donor site was repaired using a full-thickness skin graft.

Figure 5. All finger functions remained normal without any limitations or contractures in the late follow-up period.

flap. The flap was raised on the extensor tenosynovium from the dorsum to the volar side on the flexor digitorum profundus tenosynovium, ensuring at least 4 mm of soft tissue was preserved around the pedicle to protect venous return during dissection (Fig. 2c,d). Bone graft was adapted to the defect area with two 4-0 polydioxanone sutures. The defect was completely closed by moving the flap from the dorsal to the volar side (Figures 2e,f and 3). The donor area on the dorsum of the finger was repaired with a full-thickness skin graft harvested from the medial aspect of the forearm. A tie-over dressing was applied, and a short-arm relaxing splint was used for two weeks (Fig. 4). Flap perfusion was monitored by capillary refill, pulse oximeter, and finger temperature. An early period physiotherapy regime was started to prevent contractures.

RESULTS

Distal flap necrosis affecting 10-15% of the flap size was observed in one patient but healed without additional surgical intervention. No infections or venous congestion were observed. The mean static 2PD value at six months postoperatively was 5.6 mm (range: 5-7), and the mean Semmes-Weinstein monofilament (SWM) score was 3.56 (range: 3.22-4.17). The mean Cold Intolerance Severity Score (CISS) questionnaire value at one year postoperatively was 18.8 (range: 8-24). The mean active range of motion (ROM) angle of the proximal interphalangeal joint was 106.7 degrees (range: 95-115), and for the distal interphalangeal joint, it was 65.4 degrees (range: 60-70). The mean Michigan Hand Outcomes Questionnaire (MHQ) score at one year postoperatively was 18.5 (range: 8-24) (Table 2, Fig. 5).

DISCUSSION

Total or partial loss of a finger impacts patients both functionally and psychologically. Although microsurgical replantation is the gold standard, it may not always be feasible. Protection of finger length, closure with tissue similar to that of the fingertip, preservation of fingertip sensitivity, and creation of an ideal nail bed for nail growth are the main objectives of fingertip reconstruction. Fingertip reconstruction must also achieve acceptable cosmetic results and minimize labor loss by preserving joint movement.[12] Ideally, the reconstruction should be straightforward and completed in a single stage.[13] Various fingertip repair options exist for cases unsuitable for replantation.[3,14]

The V-Y advancement flap, while commonly used due to its effective sensory restoration, may not fully satisfy patients due to the limited length of advancement and insufficient tissue coverage for the pulp.[15] Additionally, scar lines extending to the touch surface can cause pain.[5]

Although cross-finger and thenar flaps can cover larger defects than the V-Y advancement flap, they require two stages and often result in poor fingertip sensation.[5] The cross-finger flap risks injury to a healthy finger, and the thenar flap frequently leads to significant proximal interphalangeal joint contractures.[16]

Homodigital island flaps are categorized as either anterograde or retrograde. Reversing the homodigital artery island flap necessitates sacrificing a normal digital artery,[17] which may lead to progressive sensation loss, cold intolerance, and hyperalgesia.[18] The blood flow of the reversed homodigital island flap, supplied by the contralateral digital artery, leads to higher rates of flow insufficiency.[19] When direct-flow is feasible, the rationale for choosing reverse flow is unclear.[20]

The free hemipulp, venous flap, and trimmed toe-tip methods are also employed for fingertip reconstruction but require advanced microsurgical techniques, making applications difficult.[7,9,10]

The length of advancement is the most important point in anterograde advancement flaps. Typically, advancement with the triangular flap described by Atasoy et al. ranges from 2-4 mm, can extend up to 12 mm with an oblique triangular flap, and may reach 19 mm with a step-advancement island flap.[21-23] Generally, a safe advancement length is considered to be 10 mm, though advancements of up to 30 mm have been achieved without complications.[24]

Our anterograde-designed flap has no limitations in terms of flap advancement. The spiral flap advances from proximal to distal and moves from the dorsal to the volar aspect, facilitating the mobilization of more flap tissue over longer distances.

Using tissue similar in structure for repairs is a fundamental principle of reconstruction. For the spiral flap, the volar-aspected tissue nearest to the injury site was used, allowing for the most similar glabrous tissue repair of the pulp.

Fingertip sensation reconstruction restoration plays a critical role in pulp repair. Compared to other pulp repair methods, anterograde advancement flap repairs are known to provide a better sensory restoration.[25] Particularly, sensory reconstruction is more straightforward in advancements shorter than 12 mm.[12] Flap neurotization is necessary for reverse flow methods in fingertip reconstruction to enhance sensation, which extends operation time and complicates the surgical procedure.[10] Our study's spiral flap features both anterograde flow and a neurovascular bundle, thus ensuring effective sensory reconstruction in the pulp.

Generally, pedicled flaps used in fingertip reconstruction fail due to pedicle torsion, spasms from pedicle dissection, or pressure exerted by the dressing during the postoperative period.[26] To prevent flap loss from venous congestion, it is recommended to preserve approximately 3-4 mm of soft tissue around the pedicle during dissectio.[27] The absence of torsion is an advantage of the anterograde flow spiral flap technique for inset step.

Lim et al. first described the spiral flap repair in fingertips,[28] and we modified the technique by adding a bone graft taken from the amputate. Fingertip reconstruction post-amputation can lead to beak nail deformity due to a lack of soft tissue and bone distally. The bone graft combined with a spiral flap provides sufficient tissue, with minimal beak nail deformities observed during long-term follow-up. No necrosis or osteitis was seen in the bone grafts. Sensation loss was detected at sites where full-thickness grafts were applied to flap donor areas. Particularly, grafts on the finger dorsum led to some dissatisfaction and a decrease in the Michigan Hand Outcomes Questionnaire (MHQ) scores among female patients, esthetically. However, patients preferred loss of sensation on the finger dorsum over loss in the fingertips. Overall, the advantages of the bone grafting combined with a spiral flap technique include preserving the normal length of the finger, providing adequate soft and bone tissue support at the fingertips, restoring good fingertip sensation through the neurovascular bundle, delivering acceptable esthetic results with glabrous skin transfer, and preventing beak nail deformity with bone graft support. Additionally, it is easy to apply, reliable, and does not require microsurgery, damage other fingers, or sacrifice the digital artery and nerve. It offers a longer advancement distance than other anterograde flap techniques.

Subjective patient evaluation of MHQ and CISS scores may be seen as a limitation of our study.

CONCLUSION

In cases of fingertip amputation or pulp defects not suitable for replantation, using the bone grafting combined with a spiral flap technique can preserve the length of the finger. This method provides adequate soft tissue support and restores finger sensation.

Ethics Committee Approval: This study was approved by the Biruni University Medical Faculty Ethics Committee (Date: 03.11.2023, Decision No: 2023-84-08).

Peer-review: Externally peer-reviewed.

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ORİJİNAL ÇALIŞMA - *ÖZ*

Parmak ucu amputasyonlarının rekonstrüksiyonunda kemik grefti ile kombine spiral flep tekniğinin kullanımı

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AMAÇ: Parmak distalinde ve pulpa defektlerinde greftleme, lokal veya uzak flep gibi farklı rekonstrüktif seçenekler mevcuttur. Normal anatomik yapının yeniden yapılandırılmasının yanı sıra parmağın duyu fonksiyonunun korunması da önemlidir. Bu çalışmada kemik kaybının eşlik ettiği pulpa defektlerinin rekonstrüksiyonunda kemik greftleme ile kombine edilmiş spiral flep tekniğinin (BGcSF) kullanım sonuçlarını sunuyoruz.

GEREÇ VE YÖNTEM: Parmak ucu defekti olan 23 hasta BGcSF tekniği kullanılarak tedavi edildi. Flep duyarlılığı ameliyat sonrası 6. ayda Semmes-Weinstein monofilament (SW) ve statik 2PD testleri ile değerlendirildi. Hasarlı parmakların soğuk intoleransı, ameliyat sonrası 1. yılda Soğuk İntolerans Şiddet Skoru (CISS) anketi ile değerlendirildi. Hasta memnuniyeti Michigan Hand Outcomes Questionnaire testi (MHQQ) kullanılarak değerlendirildi. Ameliyat sonrası 1. yılda hastaların proksimal ve distal interfalangeal eklem hareket serbestliği gonyometre ile ölçüldü.

BULGULAR: Bir hastada %10-15 oranında flep boyutunda distal flep nekrozu gözlendi. Başka bir komplikasyon görülmedi. Ameliyat sonrası 6. ayda ortalama statik iki nokta ayrım değeri 5.6 mm, ortalama SW skoru 3.56 olarak belirlendi. Ameliyat sonrası 1. yılda ortalama CISS değeri 18.8 idi. Ortalama proksimal interfalangeal eklem aktif ROM açısı 106.7 derece, distal interfalangeal eklem değeri ise 65,4 olarak belirlendi. Ameliyat sonrası 1. yıldaki ortalama MHQQ skoru 18.5 idi.

SONUÇ: BGcSF tekniği ile parmak ucuna benzer dokuya sahip yumuşak doku oluşturmak mümkündür. Bu teknik ile parmak ucunda duyu elde edilebilir. BGcSF, replantasyonun mümkün olmadığı durumlarda parmak ucu rekonstrüksiyonu için iyi bir seçenek olarak düşünülebilir.

Anahtar sözcükler: Amputasyon; kemik grefti; parmak ucu; rekonstrüksiyon; spiral flep.

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