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RESEARCH

Free toe thumb lateral pulp flap for finger pulp defect reconstruction

Parmak pulpa defektlerinin serbest ayak başparmak lateral pulpa flebi ile rekonstrüksiyonu

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Abstract

Purpose: The aim of this study was to report our outcomes of reconstruction using free thumb lateral pulp transfer in patients with finger pulp defects.

Materials and Methods: Twelve patients (nine males and three females) who presented to our clinic with pulp defects between 2015 and 2022 were included in the study. The mean age of the patients was 34 years (range, 24–46 years). Six patients had Allen type 2, four had Allen type 3, and two had Allen type 4 injuries. Pulp defects were caused by crush injuries in nine patients and sharp instrument injuries in three patients. All patients underwent free thumb lateral pulp transfer using the same surgical technique. Patients were followed in the ward and discharged at a mean of nine days (range, 8–12 days) postoperatively.

Results: None of the flaps developed total or partial loss. Venous congestion occurred in two patients. No early postoperative complications were observed in the remaining patients. One patient developed a superficial tissue infection on postoperative day 9. No donor-site complications were observed in any patient. At the final follow-up visit, only one patient had a 5° flexion contracture and a 5° flexion deficit in the distal interphalangeal joint. All other patients had a full range of motion. Sensory evaluation of the flaps was performed using the static two-point discrimination (s2PD) test and the Semmes–Weinstein monofilament (SWM) test, in comparison with the contralateral finger. The mean s2PD value of the reconstructed pulp was 4.5 mm (range, 3–8 mm), whereas it was 3 mm on the contralateral side. The mean SWM value was 3.22 g (range, 2.72–4.6 g) in the reconstructed pulp and 2.90 g on the contralateral side.

Conclusion: Reconstruction of pulp defects following acute hand injuries using free thumb lateral pulp transfer yields satisfactory functional, aesthetic, and sensory outcomes.

Keywords: Hand deformities, acquired; free tissue flaps; finger injuries

Öz

Amaç: Bu çalışmanın amacı el parmak pulpa defekti olan hastalarda serbest ayak başparmak lateral pulpa transferi ile rekonstrüksiyon sonuçlarımızı bildirmektir.

Gereç ve Yöntem: Kliniğimize 2015-2022 yılları arasında pulpa defekti ile başvuran 12 hasta (dokuz erkek, üç kadın) çalışmaya dahil edilmiştir. Hastaların ortalama yaşı 34'tür (24-46 yaş). Hastaların altı tanesi Allen tip 2, dört tanesi Allen tip 3 ve iki tanesi Allen tip 4 yaralanmadır. Pulpa defekti 9 hastada crush yaralanma ile üç hastada ise kesici alet yaralanması ile meydana gelmiştir. Tüm hastalara aynı cerrahi teknikle serbest ayak başparmak lateral pulpa transferi yapılmıştır. Servis takibi yapılan hastalar cerrahi sonrasında ortalama dokuz günde (8-12 gün) taburcu edilmiştir.

Bulgular: Çalışmaya dahil edilen hastalara uygulanan fleplerin hiçbirisinde kayıp gelişmemiştir. İki hastada flepte venöz konjesyon gelişmiştir. Diğer hastalarda erken dönemde postoperatif komplikasyon gelişmemiştir. Bir hastada dokuzuncu günde yüzeyel doku enfeksiyonu gelişmiştir. Hiçbir hastada donör saha komplikasyonu gelişmemiştir. Hastaların son kontrollerinde sadece bir hastada distal interphalangeal eklemde 5o fleksiyon kontraktürü ve 5o fleksiyon kaybı tespit edilmiştir. Diğer hastaların tamamında eklem hareket açıklıkları tamdır. Fleplerin duyu muayenesi karşı taraf parmak ile kıyaslanarak statik 2 nokta diskriminasyon testi ve Semmes- Weinstein monofilament testi ile yapılmıştır. Flep uygulanmış olan pulpaların ortalama statik 2 nokta diskriminasyonu 4.5 mm (3 ila 8 mm arası) iken karşı tarafta ortalama 3 mm dir. Ortalama Semmes- Weinstein monofilament testleri flep uygulanmış olan pulpada 3.22 g (2.72 ila 4.6 g) iken karşı tarafta ortalama 2.90 g dir.

Sonuç: Akut el yaralanmaları sonrası oluşan pulpa defektlerinin serbest ayak başparmak lateral pulpa transferi ile rekonstrüksiyonu fonksiyonel, estetik ve duyusal anlamda tatminkar sonuçlara sahiptir.

Anahtar kelimeler: El deformiteleri, kazanılmış, serbest doku flepleri, parmak yaralanmaları

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INTRODUCTION

Acute hand injuries frequently result in fingertip pulp defects, leading to considerable functional impairment. Such injuries may result in permanent pulp deficiencies and significantly compromise digital function. The Allen classification is one of the most widely used systems for categorizing fingertip injuries and pulp defects in clinical practice[1]. This classification is based on the anatomical extent of tissue loss and provides a practical framework for guiding treatment decisions and predicting functional outcomes. According to this system, Type I injuries are limited to the pulp without involvement of the nail bed or bone. Type II injuries involve both the pulp and the nail bed, often resulting in more complex soft tissue defects. Type III injuries are characterized by partial loss of the distal phalanx in addition to pulp and nail bed involvement, which may significantly affect fingertip stability and function. Type IV injuries represent the most severe form, extending proximal to the lunula and involving substantial loss of soft tissue and bony structures. The Allen classification not only facilitates standardized assessment of injury severity but also plays a critical role in determining the most appropriate reconstructive approach (Figure 1)[1,2].

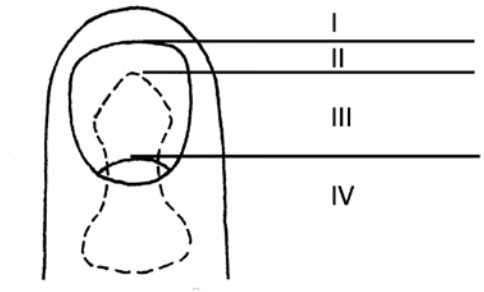

Figure 1. Allen classification

(Type I injuries are confined to the pulp; Type II injuries involve both the pulp and the nail bed; Type III injuries entail partial loss of the distal phalanx; and Type IV injuries involve injury proximal to the lunula).

Numerous reconstructive techniques have been described for pulp defects, including skin grafts, regional flaps, and free flaps, all of which are routinely used in clinical practice[2] Treatment selection may vary depending on injury characteristics, patient-related factors, sociocultural considerations, available resources, and surgeon experience.[3] In previous studies, the outcomes of fingertip reconstruction have been commonly evaluated using objective sensory tests such as static and moving two-point discrimination, Semmes–Weinstein monofilament testing, as well as functional parameters including range of motion, return-to-work time, and patient-reported outcome measures. These metrics are essential for assessing both sensory recovery and overall functional restoration[3-5].

In recent years, patient-centered outcomes and aesthetic satisfaction have gained increasing importance in addition to traditional functional measures. In a study conducted by Smith et al., it was demonstrated that sensory recovery alone does not fully reflect patient satisfaction; factors such as scar quality, cold intolerance, and fingertip contour play a significant role in long-term outcomes[6]. Furthermore, advances in microsurgical techniques and perforator-based flaps have expanded reconstructive options and enabled better preservation of tissue characteristics and vascular integrity. Lee et al. reported that perforator flaps may provide superior sensory recovery and lower donor-site morbidity compared to conventional techniques[7]. In addition, emerging evidence indicates that early rehabilitation protocols and multidisciplinary management approaches significantly enhance functional recovery and shorten return-to-work duration, particularly in complex fingertip injuries[8].

The primary objectives of pulp defect reconstruction are to provide durable skin coverage, restore a natural pulp contour, preserve digit length, and achieve optimal functional and sensory recovery. Minimizing donor-site morbidity is also a critical consideration in this restorative process. Free pulp transfer from the toe to the hand represents a favorable reconstructive option due to the glabrous skin and specialized adipose architecture of the toe pulp. In addition, its close contour similarity to the finger pulp and the possibility of neurotization through inclusion of the digital nerve provide distinct advantages over alternative reconstructive methods[3,9].

Compared to existing literature, this study provides a more homogeneous analysis by limiting inclusion to single-digit acute injuries and applying a standardized surgical approach, thereby allowing clearer interpretation of sensory and functional outcomes. In this study, it was hypothesized that lateral free pulp transfer from the great toe would provide favorable

clinical, functional, and sensory outcomes in patients presenting with fingertip pulp defects secondary to acute hand trauma.

MATERIALS AND METHODS

The study was conducted at a tertiary care center, Private Middle East Hospital, between 2015 and 2022. All clinical procedures were performed in accordance with institutional standards and established surgical protocols. Data reliability was ensured through standardized data collection processes, consistent application of surgical techniques, and retrospective review of patient records. All surgical procedures (including recipient site preparation, flap elevation, and microvascular anastomoses) were performed by a single experienced Orthopaedics and Traumatology specialist MD to ensure procedural consistency. Postoperative care and follow-up were carried out by the same physician. Rehabilitation processes were performed by an independent physiotherapist who was not involved in the study. Data collection and analysis were conducted by the researchers in accordance with predefined protocols, ensuring consistency and accuracy throughout the study process.

Ethics committee approval was obtained from the Ethics Committee of Private Ortadoğu Hospital at its meeting held on June 3, 2023 (decision no: 103) and informed consent approvals are taken from all patients. Between 2015 and 2022, 27 patients presented to our clinic with acute hand injuries associated with fingertip pulp defects underwent reconstruction with free pulp transfer.

Sample

This study has a retrospective clinical design. A post hoc power analysis was conducted following completion of the study to evaluate the adequacy of the sample size. Based on the observed data, the effect size was calculated as 0.274, and the statistical power was determined to be 95% at a significance level of $\alpha = 0.05$. Power analysis was performed using G*Power 3.1 software. The sample size consisted of all eligible patients who met the predefined inclusion and exclusion criteria during the study period (2015–2022), resulting in a total of 12 patients. Although the sample size was relatively small due to the strict selection criteria and the rarity of isolated fingertip pulp defects requiring free pulp transfer, the post hoc analysis indicated that the sample size was sufficient to detect a moderate effect size with high statistical power. Therefore, the study was considered adequately powered despite the limited number of participants.[10,11]

Inclusion criteria were defined as patients presenting with isolated single-digit fingertip pulp defects who underwent reconstruction with free lateral great toe pulp transfer between 2015 and 2022. Only patients with acute injuries and complete clinical records were included to ensure data consistency and reliable outcome assessment.

Exclusion criteria included patients with multiple-digit injuries, trauma to the potential donor foot, a history of smoking, and systemic diseases associated with peripheral microangiopathy (such as diabetes mellitus and Buerger's disease). These exclusion criteria were applied to eliminate potential confounding factors that could adversely affect microvascular circulation, flap viability, wound healing, and overall surgical outcomes. Additionally, patients with multiple injuries were excluded to maintain sample homogeneity and allow accurate evaluation of functional and sensory outcomes specific to single-digit pulp defects. Fifteen patient excluded form study (6 patient for smoking history, 4 patient for diabetes mellitus history, 1 patient for Buerger disease, 4 patient for multipl hand injury). Twelve patients (9 male and 3 female) met the inclusion criteria and were included in the study. The mean patient age was 34 years (range, 24–46 years). According to the Allen classification, injuries were categorized as follows: six Type II, four Type III, and two Type IV injuries. Injury mechanisms included crush injuries (n=9) and sharp lacerations (n=3). The affected digits were the thumb (n=4), index finger (n=7), and middle finger (n=1). The mean defect size was 388.33±72.31 mm^2 (range, 322–578 mm^2). Patients with sharp lacerations (n=3) underwent immediate reconstruction. Patients with crush injuries (n=9) underwent serial debridement prior to reconstruction, with definitive surgery performed at a mean of five days post-injury (range, 3–9 days). In all cases, a free pulp flap was harvested from the lateral aspect of the left great toe using the technique described by Wei et al.[12]

Surgical technique

All the surgeries were performed by a single surgeon including recipient dissection, flap elevation to the anastomosis and all the surgeries were done under

microscope magnification of x20 (Zeiss Tivato 700, serial number 6643142849, Carl Zeiss Meditec AG). All procedures were performed under general anesthesia. Initial debridement and preparation of the recipient site were carried out. A zigzag incision was extended proximally from the defect margins to expose the digital neurovascular structures. Suitable recipient arteries and veins for anastomosis, as well as corresponding digital nerve ends, were identified, debrided, and prepared.

Harvest of the free pulp flap was initiated from the dorsal aspect of the first web space of the left foot under tourniquet control. Dissection proceeded proximally to obtain a 2-cm vascular pedicle at the confluence of the lateral digital artery of the great toe and the medial digital artery of the second toe. The accompanying vein and lateral digital nerve were subsequently isolated, and the flap was elevated. After transfer, the flap was temporarily inset at the recipient site. Under microscopic magnification, neurorrhaphy was performed first, followed by end-to-end arterial and venous anastomoses using 9-0 and 10-0 nylon sutures, respectively. In one case, an interpositional vein graft was required to achieve tension-free venous anastomosis. After confirmation of vascular patency and adequate perfusion, final flap inset was completed. The donor site was closed primarily in all patients. Postoperatively, patients received parenteral antibiotics for one week, continuous intravenous heparin infusion, and oral acetylsalicylic acid. Flap viability was monitored clinically by assessing capillary refill, color, turgor, and temperature. Rehabilitation supervised by an occupational therapist was initiated between postoperative days 5 and 7, beginning with passive mobilization. The mean hospital stay was 9 days (range, 8–12 days).

Statistical analysis

The research data were analyzed using the SPSS for Windows 22.0 statistical software package. Descriptive statistics included frequency, percentage, minimum and maximum values, mean, and standard deviation. The normality of the data distribution was evaluated based on whether the Skewness and Kurtosis coefficients were within the ±2 range.[13] For statistical analyses, the Mann–Whitney U test was used for comparisons between two groups, and the Kruskal–Wallis test was used for comparisons among multiple groups; in cases where significant differences were found, post-hoc analyses were conducted using the Mann–Whitney U test. Spearman correlation analysis was performed to determine the relationships between variables.

RESULTS

As shown in Table 1, 75% of the participants were male, 75% experienced a crush-type injury mechanism, and 58.3% had injuries involving the second finger. Among the participants, 50% had a type 2 tissue defect, 25% experienced early complications, and 91.7% had no late complications. The mean age of the participants was 34±6.95 years, the average tissue defect size was 388.33±72.31 mm², the static two-point discrimination value was 4.50±1.45 mm (normal range 2 to 5 mm), and the monofilament test score was 3.30±0.53 (normal range 1.65 to 6.65).

As shown in Table 2, the differences in two-point discrimination and monofilament scores according to tissue defect type were not statistically significant ($p>0.05$).

As presented in Table 3, there was no statistically significant relationship between the size of the tissue defect and the two-point discrimination value or the monofilament score ($p>0.05$).

No total or partial flap loss occurred. Two flaps developed venous congestion, which was successfully managed with intermittent medicinal leech therapy. No other early postoperative complications were observed. One patient developed a superficial surgical site infection on postoperative day 9, which resolved with targeted antibiotic therapy and local wound care. No donor-site complications were noted. Problems with wound healing, gait disturbances and complaints of joint stiffness at the donor site were not adressed (Figure 2).

Patients were followed for a mean of 6.5 months (range, 3–9 months). At final follow-up, interphalangeal joint range of motion (ROM) was measured using a goniometer and compared with the contralateral uninjured digits. Full ROM was restored in all patients except one. This patient, who had an Allen Type III injury complicated by superficial infection, demonstrated a 5 flexion contracture and a 5 loss of flexion at the distal interphalangeal joint.

Sensory recovery was assessed using static two-point discrimination (s2PD) and Semmes–Weinstein monofilament (SWM) testing, with the contralateral fingertip serving as a control. The mean s2PD was 4.5

mm (range, 3–8 mm) in reconstructed pulps compared with 3 mm in contralateral digits. The mean SWM value was 3.22 g (range, 2.72–4.6 g) versus 2.90 g in controls.

Table 1. Demographic and clinical characteristics of the participants

Variables				**n**	**%**
Gender	Female			3	25.0
	Male			9	75.0
Injury Mechanism	Crush			9	75.0
	Sharp Object			3	25.0
Finger	1. finger			4	33.3
	2. finger			7	58.3
	3. finger			1	8.3
Type of Tissue Defect	Type 2			6	50.0
	Type 3			4	33.3
	Type 4			2	16.7
Early Complication	None			9	75.0
	Venous Congestion			2	16.7
	Superficial Infection			1	8.3
Late Complication	None			11	91.7
	Flexion Contracture			1	8.3
Numerical Variables	n	Min.	Max.	Mean	SD
Age	12	24	46	34.00	6.95
Tissue Defect Size	12	322	578	388.33	72.31
Two-Point Discrimination	12	3	8	4.50	1.45
Monofilament Test	12	2.70	4.60	3.30	0.53

n: number; %: percentage; Min.: minimum; Max.: maximum; SD: standard deviation. * Multiple selections have been made

Table 2. Comparison of two-point discrimination and monofilament scores according to type of tissue defect

		Two-Point Discrimination			**Monofilament**		
		n	Mean	SD	n	Mean	SD
Type of Tissue Defect	Type 2	6	4.17	1.94	6	3.22	0.71
	Type 3	4	4.50	0.58	4	3.24	0.22
	Type 4	2	5.50	0.71	2	3.65	0.38
	Test and Significance	x^2_{KW}=3.564 p=0.168			x^2_{KW}=2.298 p=0.317		

n: number; SD: standard deviation; χ^2KW: Kruskal–Wallis test statistic; p: p-value.

Table 3. Analysis of the relationship between tissue defect size and two-point discrimination and monofilament score

		Two-Point Discrimination	**Monofilament Score**
Tissue Defect Size	r	0.301	0.185
	p	0.342	0.565
	n	12	12

n: sample size; r: Spearman correlation coefficient; p: p-value

Figure 2. Figure of left hand 2. finger pulp defect reconstruction with toe thumb lateral pulp.

Sensory recovery was assessed using static two-point discrimination s2PD and SWM tests. These tests were performed to evaluate the functional sensory outcomes of the reconstructed pulp tissue and to compare them with the contralateral, uninjured finger. The s2PD test was used to measure tactile spatial resolution by determining the minimum distance at which two separate points could be perceived as distinct. The SWM test was used to assess cutaneous pressure sensitivity and peripheral nerve function using calibrated monofilaments of varying thickness. All sensory assessments were performed at the final follow-up by the same experienced clinician who was not involved in the surgical procedures, in order to minimize measurement bias. Evaluations were conducted

under standardized conditions and compared with the contralateral finger to ensure objective assessment of sensory recovery.

DISCUSSION

This study demonstrates that reconstruction of significant fingertip pulp defects using free lateral great toe pulp transfer yields favorable outcomes, with low complication rates and high patient satisfaction. Postoperative evaluation revealed satisfactory sensory recovery, preservation of distal interphalangeal joint motion, and acceptable aesthetic results.

Pulp injuries are common traumatic conditions that may lead to substantial functional and cosmetic impairment of the hand. While Allen Type I injuries often heal by secondary intention or with skin grafting, Type II and more proximal injuries present greater reconstructive challenges due to larger defect size and frequent exposure of tendon, nerve, or bone. Although local flaps remain a viable option, their use is limited by compromised local tissue quality, defect dimensions, and donor-site morbidity. Additionally, flap harvest near joints carries a risk of postoperative joint contracture. Propeller flaps and other rotational techniques also pose a risk of vascular compromise due to pedicle kinking,[14-17] complications that were not encountered in our series.

Free flap reconstruction has gained popularity for complex pulp defects, particularly when deep structures are involved. However, free tissue transfer is technically demanding and associated with a steep learning curve, longer operative times, and potential donor-site morbidity when larger tissue volumes are harvested.[4,5]

Tsai et al. published their results on the use of free thenar flaps in the repair of complex soft tissue defects of the volar region of the hand.[17] One of the major advantages of this technique is its ease of use, as the flap can be harvested from the same surgical site without requiring additional donor area preparation, thereby potentially shortening the operative time. However, its main disadvantage lies in its poor innervation, which results in diminished sensory recovery.[18] In recent years, to enhance innervation, the thenar flap has been modified into the SUPBRA flap, which is based on the superficial palmar branch of the radial artery, the flap's pedicle.[19] If the donor area of this flap is smaller than 2 cm^2, primary closure is possible. Another surgical option used for pulp reconstruction is the free hypothenar flap, described by Kim et al. in 2013. Its location within the same operative field represents a significant advantage. However, the difficulty in dissecting the flap's pedicle and the frequent complications associated with microanastomosis are notable disadvantages. Additionally, the bulky subcutaneous tissue often necessitates volume reduction, and suturing the flap to the pulp region frequently requires placing the sutures under tension, which further complicates the procedure.[20,21]

Among available free flap options, toe pulp tissue provides the closest match to fingertip pulp in terms of contour, texture, and tissue composition. Originally described by Buncke and Rose in 1979, the free toe pulp flap offers glabrous skin and a specialized subcutaneous fat architecture that closely resembles native finger pulp.[22] Moreover, transfer as a neurovascular flap enables excellent sensory restoration.

In our series, early venous congestion occurred in only two patients and was successfully managed with leech therapy. In these patients. it was thought that the relatively large size of the flaps and the possible compression of veins caused venous congestion. One patient experienced a superficial infection, followed by mild distal interphalangeal joint stiffness, which we attribute to delayed rehabilitation. No other complications were observed.

This study has several limitations. First, the small sample size may limit the generalizability of the findings. Second, the retrospective design limits study control. Third, the absence of a control group prevents direct comparison with alternative reconstructive techniques. Fourth, the relatively short follow-up period (mean 6.5 months) may be insufficient to evaluate long-term functional and sensory outcomes. Finally, patient-reported outcomes were not assessed. Future studies with larger sample sizes, control groups, and longer follow-up periods are needed to confirm these findings.

Despite limitations including small sample size, lack of long-term follow-up, single center experience and absence of a control group, our findings support the reliability and effectiveness of free lateral great toe pulp transfer for selected fingertip injuries.

Free lateral great toe pulp transfer is a reliable reconstructive option for acute fingertip pulp defects, providing acceptable functional, sensory, and

aesthetic outcomes. Further comparative studies with larger cohorts and longer follow-up are warranted. In conclusion, free lateral great toe pulp transfer appears to be a reliable and effective option for the reconstruction of fingertip pulp defects, providing satisfactory functional, sensory, and aesthetic outcomes. The technique offers a close tissue match and supports favorable recovery with low complication rates. Future research should focus on prospective, controlled, and multicenter studies to compare this technique with alternative reconstructive methods. In addition, studies with larger sample sizes and longer follow-up periods are needed to better evaluate long-term outcomes, including sensory recovery, functional performance, and patient satisfaction. The inclusion of standardized patient-reported outcome measures may further contribute to a more comprehensive understanding of treatment effectiveness.

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