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Composite classification and algorithmic reconstruction of fingertip defects with free lateral great toe flaps

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Summary *Background:* This study aimed to classify fingertip defects according to dimensions and composite content, and present algorithmic reconstruction results with free lateral great-toe flaps.
Methods: A total of 33 patients who underwent reconstruction for full-thickness defects of fingertips with free lateral great-toe flaps were retrospectively reviewed. Patients were divided into four groups by the algorithm according to the dimension and content of defects. Functional disabilities of the upper extremities, limitations of donor feet, finger cosmetics, sensory recovery, and pinch power were evaluated using the disabilities of the arm, shoulder and hand, foot function index, 5-point Likert satisfaction scales, Semmes-Weinstein monofilament and static 2-point discrimination tests, and pulp pinch-strength test, respectively.
Results: The standardized distribution of patients according to dimensions and content of defects was achieved. When the composite content of defects increase such as group 4, complex surgical skills are required, duration of surgery is extended, return to work is delayed, and donor-site complications are increased. Functional limitations of the hands improved normally after reconstruction ($p < 0.00$). Sensory recovery of flaps was normal and test scores were strongly correlated ($p = 0.78$). All patients and observers were satisfied with finger's cosmetics.
Conclusion: Our classification and reconstruction algorithm is simple and easy to apply for all fingertip defects without complicated reference points, and it provides information about the surgical and post-surgical periods. When the dimension and composite deformities of the defect increase through groups 1–4, more complex reconstruction, increased donor-site complications, prolonged duration of surgery, and delayed return to work are observed.

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The fingertip is the most commonly injured part of the hand. Depending on the type and severity of the trauma, fingertip defects may occur in various localizations and tissue involvements.[1-6] Fingertip defects have been previously classified; however, most of them describe distal to proximal transverse amputation levels using anatomic landmarks such as the nail, branches of digital arteries, tendons, distal phalanx, and joint.[1-3,7-13] Fingertip injuries do not always present as distally located clean-cut amputations. It can be referred to as oblique and irregularly shaped, proximally located soft tissues or composite defects after crush and avulsion injuries.[3] Thus, it is challenging to determine the reference landmarks and categorizations of these defects using classical classifications. Additionally, the reconstruction algorithm of these defects is controversial with classical classifications, owing to various locations and composite tissue involvements.

Reconstruction of the fingertip is not only to close defects but also to cover bone and ligamentous structures with well-vascularized tissue padding, preserve length and sensory functions, support the nail bed, and create functional and esthetic fingertips.[3,4,13-16] Thus, only another fingertip tissue based on "repair like with like" principle can meet these requirements.[14,16] For this purpose, Buncke and Rose[17] described free toe pulp transfer and various modifications[3,4,13,14,16,18,19] that have been used for fingertip reconstruction when local options were unavailable or inadequate.

This study aimed to classify fingertip defects according to dimensions and composite tissue involvements as well as present esthetic, functional, and sensorial outcomes of algorithmic reconstruction with free lateral great-toe flaps.

Methods

From November 2018 to September 2020, 33 patients who underwent reconstruction for crush and full-thickness defects of fingertips with free lateral great-toe flaps were retrospectively reviewed. Small and superficial fingertip defects that can be closed with primary, secondary intention, skin grafts, local pulp and regional flaps, distal phalanx total amputations, and accompanying upper and lower extremity injuries were not included in the study (Figure 1). All patients enrolled provided written and verbal informed consent before surgery. The study was conducted in compliance with the principles of the Declaration of Helsinki and approved by the local ethics committee.

Defects were divided into four groups according to the dimension and composite involvement of defects (Figure 1). Groups 1-2 were classified as isolated pulp defects affecting $< 50\%$ ($n = 11$, group 1) or $\geq 50\%$ of the fingertip ($n = 8$, group 2), and groups 3-4 were classified as composite defect affecting $< 50\%$ ($n = 8$, group 3) or $\geq 50\%$ of the fingertip, including the pulp, bone, nail bed, and/or tendon defect ($n = 6$, group 4). Groups 1-2 and 3-4 were reconstructed with free lateral great-toe pulp and composite flaps, respectively (Figure 2).

Demographic characteristics of patients, comorbidities, injury mechanisms, characteristics of defects and flap, duration of surgery, complications, return-to-work, and follow-up period were compared between the groups (Tables 1 and 2).

Before and at 12 months after surgery, functional disabilities of the injured hand and limitations of donor toes were evaluated using the disabilities of the arm, shoulder, and hand (DASH) and foot function index (FFI) by patients. At 12 months post surgery, the cosmetics satisfaction about color, texture, length, and symmetry of fingertips were scored by referring to the opposite fingers and using 5-point Likert satisfaction scales (1: unsatisfied; 2: indecisive; 3: moderate satisfied; 4: good satisfied; 5: excellent satisfied) by patients and two observers selected from independent plastic surgeons with at least 5 years of experience. Additionally, flap sensation and pinch strength power were respectively evaluated by a hand therapist using the Semmes-Weinstein monofilament (SWM), static 2-point discrimination (s2PD), and pulp pinch strength test (Table 2).

Surgical technique

Surgery was performed using previously reported techniques[13,14,17-21] under general anesthesia. After debridement, defect dimensions and tissue deficiencies were determined. The recipient digital neurovascular structures were dissected proximal to the traumatic zone. Flaps were designed on the lateral aspect of the nondominant great-toe in 31 patients and of the dominant great-toe in two with a counter located nail and bone defect. The first dorsal metatarsal artery was traced by Doppler ultrasound, and its web branches, volar and dorsal well-caliber veins, and digital nerve were dissected with a sufficient pedicle length. In composite defects, the nail and tendon were separated using a scalpel and distal phalanx using an oscillating saw. Harvested flaps were adapted to fingertip defects without tension. K-wires or sutures were used for bone fixation. End-to-end anastomosis was performed on the artery, two veins, and a nerve to digital neurovascular structures. The donor site was primarily closed by advancing the local tissue. Partial joint-harvested great-toes were stabilized using K-wires. The recipient and donor areas were dressed and splinted in the anatomical positions.

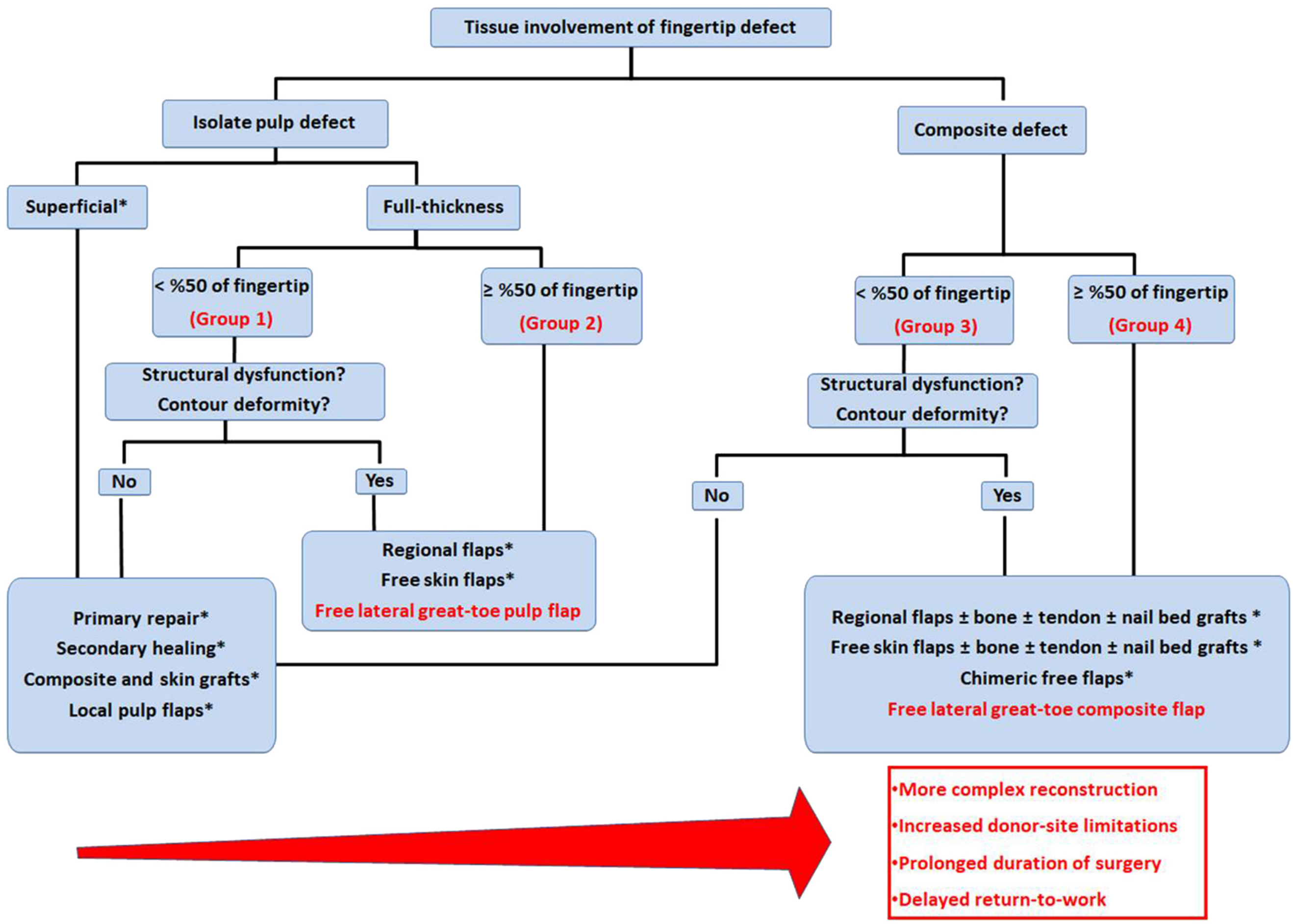

Figure 1 Classification of fingertip defects in four groups according to dimensions and composite tissue involvements, and algorithmic reconstruction with free lateral great-toe flaps. When the dimension and composite tissue loss of the defect increase through groups 1-4 (direction of the red arrow), more complex reconstruction, increased donor-site limitations, prolonged duration of surgery, and delayed return-to-work were observed. * Small and superficial defects that do not cause deformity and dysfunction of the fingertip can be reconstructed with primary repair, secondary intention, composite and skin graft, local pulp and regional flaps, and large and complex defects reconstructed by combining bone, tendon, and nail bed grafts with regional and free flaps were not included in the study.

Post-surgical follow-up

The patients were mobilized on the first day. Splints were removed, and the patients were discharged in the first week. Patients were referred to early physical therapy and tactile re-education exercises.[14,16]

K-wires were removed from donor toes at the third week and from recipient fingers at 5.4 ± 0.89 (4-8) weeks after radiological union confirmation. Patients were followed up for 17.5 ± 3.9 (12-27) months.

Statistical analysis

Statistical analyses were performed using SPSS 22.0 (IBM Corp, Armonk, NY, USA). Differences between the mean age, defect dimension, surgery duration, and return-to-work in the groups were evaluated using one-way ANOVA and post-hoc Tukey test. The relationship between SWM and s2PD scores was evaluated using Pearson's correlation coefficient. Differences between pre- and post-surgery DASH and FFI scores were evaluated using a dependent sample *t*-test. An independent sample *t*-test was used to compare the pinch strength scores between the reconstructed and opposite hands, and Likert satisfaction scores between patients and observers. Statistical significance was set at $p < 0.05$.

Results

Demographic characteristics

Thirty-three patients, 23 male and 10 female, were included in the study. The mean age was 36.8 ± 11.2 years, the majority of them were young and middle-aged with no significant

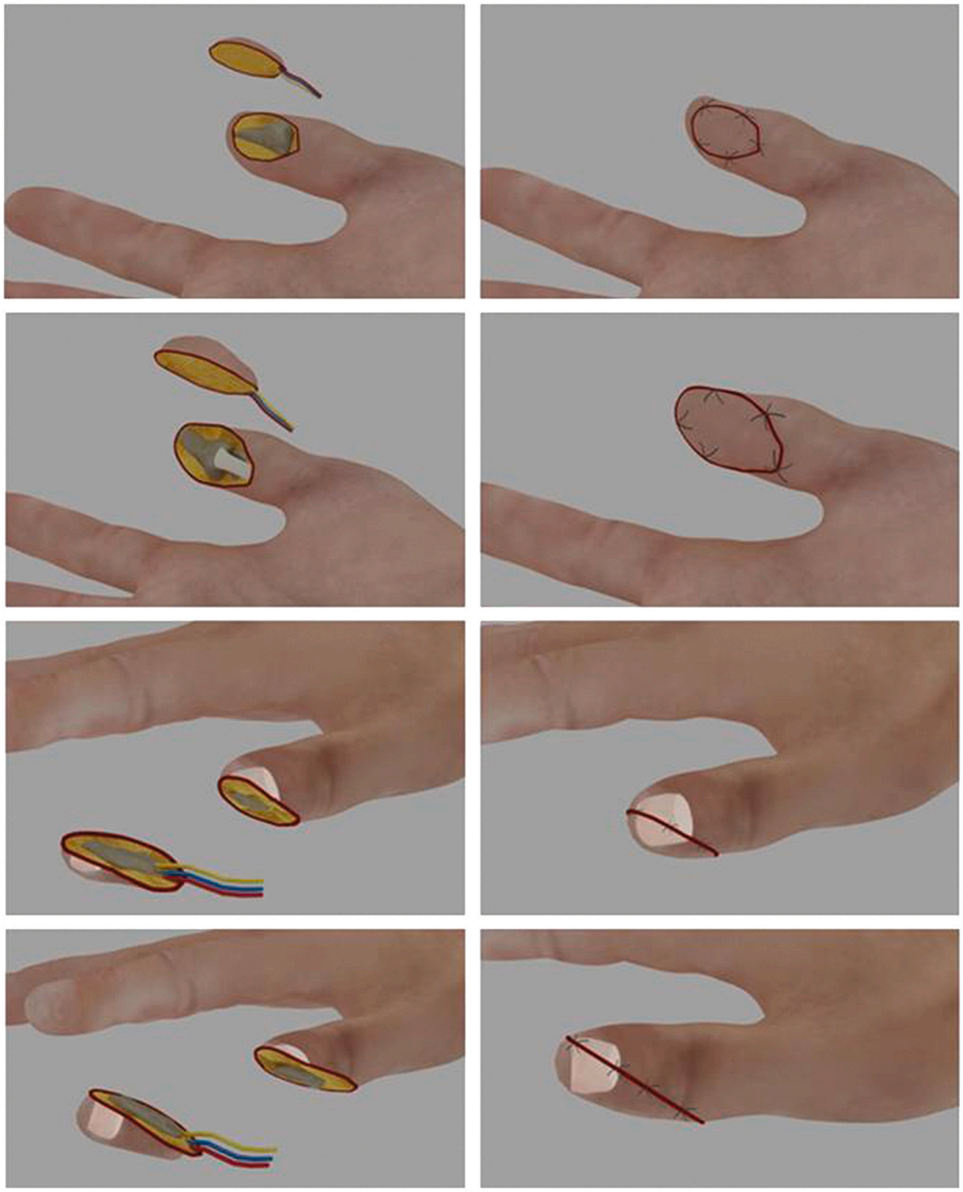

Figure 2 Illustration demonstrating the algorithmic reconstruction of fingertip defect by free lateral great-toe flaps in (above, left and right) group 1, (second from above, left and right) group 2, (second from below, left and right) group 3, and (below, left and right) group 4.

difference between the groups (pANOVA=0.59, pTUKEY > 0.05). The patients were smokers (n = 10) and had hypertension (n = 5), diabetes (n = 4), and heart disease (n = 2).

Preoperative characteristics

Twenty patients had fingertip defects on right hand, whereas 13 had defects on left hand. The etiologies included crush injury (n = 13), crush amputation (n = 8), clean-cut amputation (n = 5), injection injury (n = 4), and gunshot injury (n = 3). Among amputations, amputated stump was either absent (n = 5), non-replantable (n = 6), or our failed replantation (n = 2).

Postoperative complications

In the early postoperative period, venous insufficiency developed in three patients, two of which resolved spontaneously within 48 h, and partial distal flap necrosis developed in one patient. Donor-site dehiscence was observed in five patients and was higher in isolated pulp flaps than in composite flaps but was not related to flap dimensions. Partial necrosis and dehiscence were closely related to smoking and were treated with debridement and primary sutures. Early pin tract infection and late hyperalgesia developed in the donor toe of the same patient. The pin was removed, and infection was treated with oral antibiotics; hyperalgesia resolved spontaneously within 4 months. Cold

Table 1 General characteristics of patients, injuries, defects, flaps, and surgeries.

Case	Age (years)	Sex	Comorbidities	Type of injury	Localization of defect	Dominant hand	Fingertip percentage of defects	Content of defect	Dimension of defects (cm^2)[a]	Duration of surgery (min)	Complications
1	26	M	-	Injection	R, index	R	33	Soft tissue	1.7	145	-
2	31	M	S	Crush injury	R, thumb	R	45	Soft tissue	3.15	133	Donor area dehiscence
3	23	F	-	Crush injury	R, index	R	38	Soft tissue	1.65	122	-
4	37	M	S	Clean cut	L, index	L	35	Soft tissue	1.5	127	-
5	26	M	-	Crush injury	R, index	L	40	Soft tissue	1.6	138	-
6	22	F	-	Clean cut	L, middle	R	45	Soft tissue	2.8	141	Cold intolerance
7	52	M	HT, DM, HD	Crush injury	L, ring	R	40	Soft tissue	2.16	135	Venous insufficiency, donor area dehiscence
8	56	M	HT	Crush amputation	L, thumb	R	45	Soft tissue	3.84	155	-
9	28	M	-	Injection	L, index	R	35	Soft tissue	1.5	144	-
10	57	M	-	Crush injury	L, ring	R	33	Soft tissue	1.4	118	-
11	60	M	HT, HD	Clean cut	R, index	R	40	Soft tissue	1.54	150	-
12	28	M	DM, S	Injection	L, index	L	60	Soft tissue	3.52	132	Donor area dehiscence
13	48	F	S	Clean cut	R, ring	R	65	Soft tissue	3.75	157	Venous insufficiency, partial flap necrosis
14	28	F	-	Crush amputation	R, middle	R	80	Soft tissue	4.94	124	-
15	32	M	-	Crush injury	R, thumb	L	75	Soft tissue	6	152	-
16	38	M	-	Injection	L, middle	R	74	Soft tissue	4.4	143	-
17	44	M	S	Crush injury	L, thumb	R	70	Soft tissue	4.32	170	Venous insufficiency
18	55	F	S, HT, DM	Crush amputation	R, thumb	R	76	Soft tissue	3.75	121	Donor area dehiscence
19	40	M	-	Clean cut	R, middle	R	70	Soft tissue	3.3	135	-
20	27	M	-	Crush injury	L, middle	R	40	Soft tissue, distal phalanx, nail, extensor tendon	2.8	224	-
21	28	F	-	Crush injury	R, thumb	R	33	Soft tissue, distal phalanx	3	210	Cold intolerance
22	32	F	S	Crush amputation	R, index	L	35	Soft tissue, distal phalanx, nail	2.88	255	-
23	38	M	-	Crush amputation	R, thumb	R	40	Soft tissue, distal phalanx, nail, extensor tendon	3.08	238	-
24	25	M	-	Crush injury	R, middle	R	30	Soft tissue, distal phalanx, nail	3	221	-
25	33	F	S	Crush injury	R, thumb	R	33	Soft tissue, distal phalanx	2.94	240	-

(*continued on next page*)

Table 1 (*continued*)

Case	Age (years)	Sex	Comorbidities	Type of injury	Localization of defect	Dominant hand	Fingertip percentage of defects	Content of defect	Dimension of defects (cm^2)[a]	Duration of surgery (min)	Complications
26	42	M	HT	Gunshot	L, thumb	R	40	Soft tissue, distal phalanx	3	245	-
27	31	M	-	Crush amputation	R, index	R	40	Soft tissue, distal phalanx, nail	2.66	263	-
28	51	M	S	Gunshot	L, thumb	L	70	Soft tissue, distal phalanx, nail	5.6	268	Donor area dehiscence, pin tract infection in donor area, hyperalgesia
29	40	M	-	Crush injury	R, middle	R	75	Soft tissue, distal phalanx, nail	5.5	261	-
30	23	F	-	Crush amputation	R, thumb	L	65	Soft tissue, distal phalanx, nail, collateral ligament	6.3	284	Cold intolerance
31	35	M	-	Crush injury	L, thumb	L	70	Soft tissue, distal phalanx, extensor tendon	4.4	225	-
32	48	F	DM	Gunshot	R, index	L	80	Soft tissue, distal phalanx, nail	5.6	234	-
33	29	M	S	Crush amputation	R, thumb	R	75	Soft tissue, distal phalanx, nail, extensor tendon	5	241	-

DM, diabetes mellitus; F, female; HD, heart disease; HT, hypertension; L, left; M, male; R; right; S, smoker.
[a] The dimensions of defects and flaps were equal.

Table 2 The follow-up period, results of flap sensations, hand and foot functions, and patient satisfaction.

Case	Return to work (week)	Follow-up (month)	SWM score	s2PD score (mm)	DASH score (Pre-op)	DASH score (12th month)	FFI score (12th month)	Likert patient score (12th month)	Likert observer score[a] (12th month)	Pulp pinch test (kg)	Opposite pulp pinch test (kg)
1	4	21	2.83	3	79.1	8.3	0.42	5	5	7.1	6.3
2	5	15	3.61	5	85.8	4.2	0	5	4.5	7.5	7.7
3	5	18	3.22	4	75.8	5	0	5	5	5.1	4.2
4	3	12	2.83	3	76.7	6.7	0.2	5	4.5	6.4	6
5	4	20	3.22	4	72.5	4.2	0	5	5	5.3	6.4
6	5	16	2.83	3	73.3	8.3	0.33	5	5	4.1	4.9
7	4	23	3.22	4	84.2	7.5	0	4	4.5	3.6	5.3
8	5	19	2.83	3	88.3	6.7	0	5	5	4.9	6.5
9	5	23	3.22	4	83.3	3.3	0.33	5	5	7	8.3
10	3	15	3.61	4	75.8	6.7	0.2	5	4	3.5	7.2
11	4	12	3.61	5	81.7	7.5	0	5	5	6.3	5.1
12	7	18	3.22	4	80	5	0	4	4.5	7.3	6.8
13	6	22	3.84	6	88.3	4.2	0.2	5	5	3.6	4.2
14	4	15	2.83	4	75	5.8	0	5	5	5.1	4.5
15	5	19	2.83	4	92.5	6.7	0.67	5	5	6.5	7.1
16	4	14	3.22	4	85.8	7.5	0	5	4.5	5.5	7.7
17	7	20	3.61	5	89.2	8.3	0.42	5	4.5	6	6.8
18	7	16	2.83	3	82.5	9.2	0.33	5	5	5.1	4.5
19	4	14	3.61	5	88.3	12.5	0.42	4	5	6.5	5.4
20	10	13	2.83	4	84.2	3.3	1.59	5	4.5	5.3	6.7
21	8	16	3.61	5	93.3	6.7	0.84	5	4.5	5.4	4.4
22	7	12	3.22	4	89.2	11.6	0.67	5	5	4.2	5.3
23	10	20	2.83	3	92.5	2.5	1.83	5	5	7.8	7.1
24	9	14	3.22	4	75.8	14.2	1.2	5	5	6.8	6.4
25	8	20	3.84	5	85.8	10	0	5	5	4.1	4.2
26	9	18	3.22	4	88.3	12.5	2.46	4	4	4.9	5.5
27	7	25	3.61	5	92.5	6.7	1.67	5	5	7.2	7.5
28	10	16	2.83	3	93.3	9.2	2.08	5	5	6.4	6.1
29	8	13	3.22	4	88.8	13.3	2.3	5	5	6.5	5.3
30	10	21	3.22	4	84.2	8.3	2.61	5	5	4.3	6.2
31	9	17	3.22	4	89.2	11.6	3.63	5	5	7.2	6.6
32	7	27	2.83	4	79.1	6.7	1.58	5	4.5	3.4	4.3
33	9	15	3.61	5	92.5	9.2	1.75	5	4.5	6.4	7.1

[a] Observer satisfaction scores were averaged.

intolerance developed in three patients and spontaneously resolved at 3, 5, and 6 months postoperatively.

Groups characteristics and comparison outcomes

Defects percentages and dimensions in groups 1-4 were 39% ± 4.6, 71.2% ± 6.4, 36.4% ± 4.1, 72.5% ± 5.2, and 2.1 ± 0.8, 4.2 ± 0.9, 2.9 ± 0.1, 5.4 ± 0.6 cm^2, respectively. Differences between groups 1 and 2 (isolated pulp defects, pTUKEY=0.0001) and between groups 3 and 4 (composite defects, pTUKEY=0.0001) were significant, indicating a standardized distribution of defects in groups.

Surgical duration was the shortest in group 1 (137.1 ± 11.5 min) and the longest in group 4 (252.2 ± 22.5 min). There was no significant difference between groups 1 and 2 ($p = 0.78$) and between groups 3 and 4 (pTUKEY=0.29). However, differences between groups 1 and 3 (pTUKEY=0.001) and between groups 2 and 4 (pTUKEY=0.001) were significant.

Bone union in groups 3 and 4 was similar and completed in an average of 5.7 ± 0.72 (5-6) weeks. Durations of return-to-work were significantly different in groups 1-4 (4.3 ± 0.8, 5.5 ± 1.4, 8.5 ± 1.2, 8.8 ± 1.2 weeks; pANOVA < 0.00001). Particularly, differences between groups 1 and 3 (pTUKEY=0.0001) and between groups 2 and 4 (pTUKEY=0.0001) were significant.

According to SWM scores, sensory recovery was normal in 33% (2.83), light touch was decreased in 61% (3.22-3.61), and protective touch was decreased in 6% (3.84) of transferred fingertips. These values were strongly correlated with s2PD scores (4.09 ± 0.77, $p = 0.78$) with no significant difference between the groups.

Preoperatively, severe functional limitations of the hands improved after reconstruction (mean preoperative DASH: 84.4 ± 6.4; postoperative DASH: 7.7 ± 3), and the improvement was significant in all groups ($p < 0.001$). At 12 months, donor foot limitation was significantly higher in group 4 than in the other groups ($p_{TUKEY} < 0.00001$), but it did not affect daily and work life.

All patients and observers were good and excellent satisfied with reconstructed finger's cosmetics (patient-Likert: 4.88 ± 0.33, observers-Likert: 4.77 ± 0.33) with no significant difference in all groups ($p_{Groups\ 1-4}$=0.16, 0.37, 0.25, 0.07). The color and texture between the flaps and surrounding fingertip matched well. Secondary fingertip deformities such as clubbing, pulp enlargement, and contour irregularities were not observed.

Pinch strength scores of 28 patients (14 dominant and 14 nondominant hand injuries) were higher in the dominant hand, whereas scores of the five dominant hand injuries were lower than those of the nondominant hand. However, the mean pinch strength scores (5.65 ± 1.3 kg) were not statistically different from the opposite healthy hand in all groups (5.99 ± 1.19) ($p_{Groups\ 1-4}$=0.13, 0.39, 0.39, 0.37).

One case from each group is shown in Figures 3, 4, 5 and 6, respectively.

Discussion

The earlier established classifications of fingertip defects[1,2,7-11] were only concerned with transverse clean-cut amputation according to anatomical reference points and provided little information about the dimension and complexity of defects, nonreplantation reconstruction options, and difficulties encountered during follow-up.

Evans and Bernardis[9] described pulp-nail-bone classification using level and angle fingertip defects; Tang et al.[3] classified according to the amputation level and shape of the defects. However, these studies are complex and used multi-subdivision classification, challenging clinical applicability; the dimensions of defects, reconstruction options, and follow-up outcomes were excluded.

Our classification and reconstruction algorithm is simple and easy to apply for all fingertip defects without complicated reference points and provides information about dimensions and composite tissue involvements of defects and flaps, the surgical and post-surgical difficulties and complications. We aimed to categorize fingertip defects according to the dimensions and composite involvements, independent of the level. The isolated pulp defects were evaluated in two groups according to defect dimensions. In group 1 defects, majority of the pulp were intact, defects were < 50%, and defects were closed with primary, secondary intention, and local flaps. However, reconstruction with free flaps is recommended in group 1 and 2 defects when local and regional flaps are unavailable due to crush injury or loss of majority of the pulp.

Dorsal oblique defects, including nail bed, bone and minimal soft tissue injuries, were classified in group 3. Small composite defects that do not cause deformity and dysfunction can be reconstructed using primary, secondary intention, local and regional flaps. However, group 3 and 4 defects that cause cosmetic and dysfunctional problems require complex composite reconstruction with free flaps that can meet all tissue requirements.

When the dimension and composite tissue loss of the defect increase through groups 1-4, more complex reconstruction, increased donor-site limitations, prolonged duration of surgery, and delayed return-to-work were observed. The increased donor-site limitations and prolonged surgical durations were related to harvesting composite flap, and challenging surgical techniques and instruments during composite flap surgeries rather than flap dimensions. Delayed return-to-work was related to composite involvement of defects due to bone union and physical therapy without dimensions.

Various techniques have been described for fingertip reconstruction, depending on the dimension, localization of defect, availability of remaining tissue, surgeon's experience, and patient's expectations.[3-6,8,13,14,18,22] The primary aim was to homogeneously distribute the

Figure 3 (Case 2). (Left) Full-thickness crush defect of the right thumb in group 1 defects. (Right) At 1-year follow-up, reconstruction results with free lateral great-toe pulp transfer. The flap was well-adapted to the thumb, sensory recovery was good, only light touch decreased, significant upper extremity disability was not observed, finger pinch strength was within normal limits, and patient and observers were very satisfied with the cosmetic outcomes.

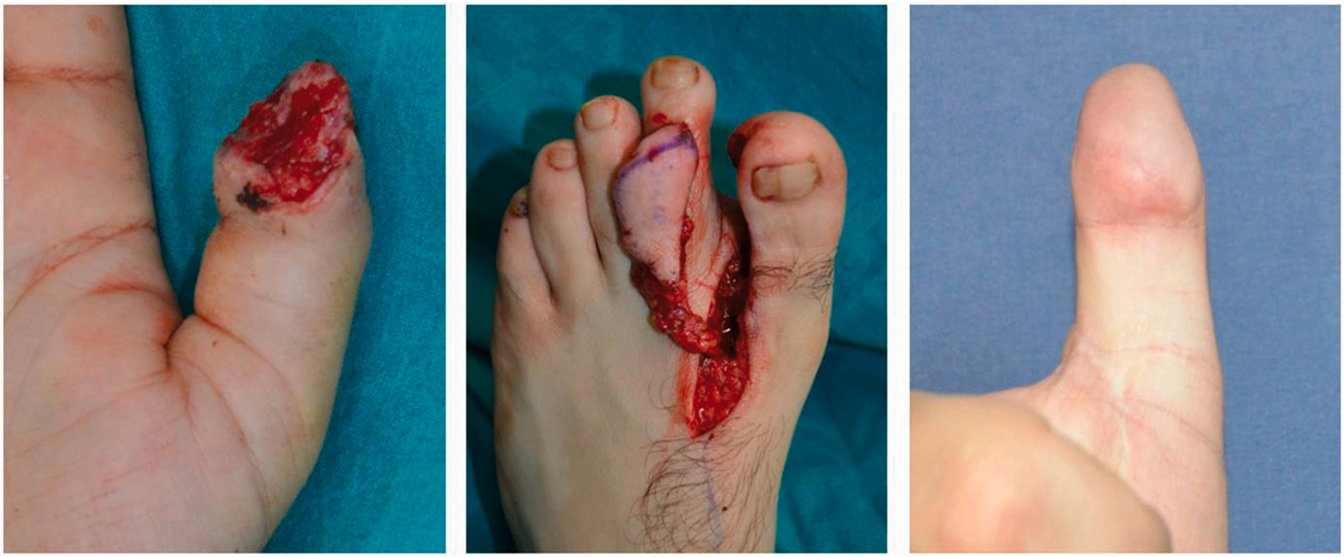

Figure 4 (Case 15). (Left) Full-thickness pulp amputation of the nondominant right thumb in group 2 defects. (Center) Lateral great-toe pulp flap harvested from the nondominant left great-toe. (Right) At 1-year follow-up, the flap was well-adapted to the thumb, flap sensory recovery was normal, significant upper extremity disability was not observed, finger pinch strength is close to normal, and patients and observers were very satisfied with the cosmetic outcomes.

remaining pulp tissue with a local flap. Local flaps are easy to apply and are reliable options for small distal defects but are insufficient for large, proximally located, and composite defects.[3,23,24]

Homodigital and heterodigital islands and perforator flaps can provide one-stage repair in the same surgical field. However, insufficient fullness of the pulp, skin grafting to the donor area, venous return problems, cortical sensory adaptation problems, hyperesthesia, persistent cold intolerance, inadequacy in composite defects, and scarring contracture along the volar aspect of the finger are the main disadvantages.[3,13,17,25,26]

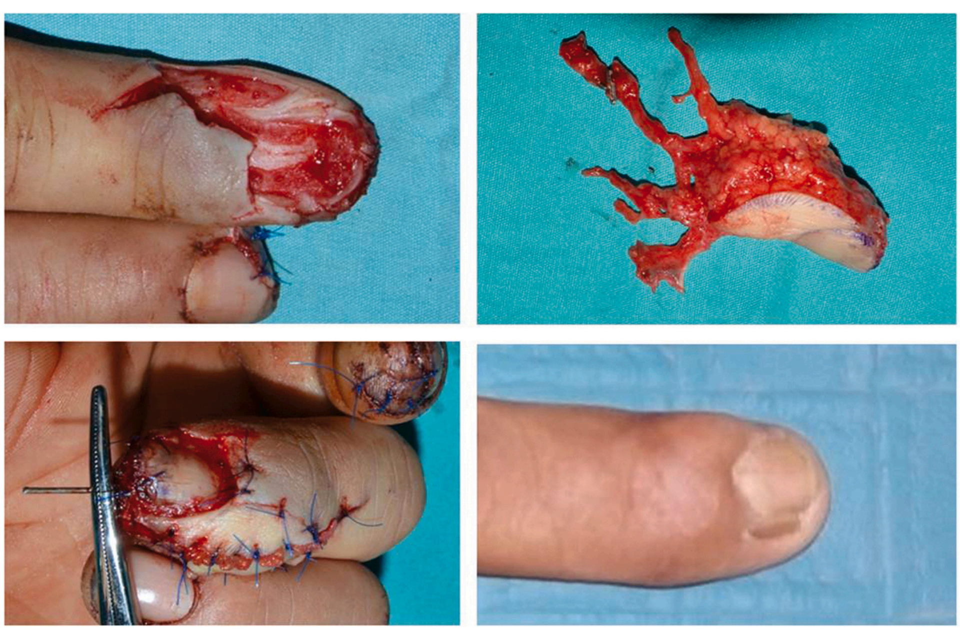

Figure 5 (Case 20). (Above, left) Composite fingertip defect accompanying the dorsal part of the distal phalanx, extensor tendon, nail, and skin < 50% of the third finger of the nondominant left hand in group 3 defect after crush injury. (Above, right) Defect was reconstructed with composite fingertip flap containing bone, tendon, nail, and skin harvested from the nondominant left great-toe. (Below, left) The composite flap was stabilized using K-wire. (Below, right) At 1-year follow-up, the composite flap was well-adapted to the recipient finger, flap sensory recovery returned to normal, upper extremity disability, and significant limitation in donor foot were not observed, finger pinch strength was close to normal, and patients and observers were very satisfied with the cosmetic outcomes.

Figure 6 (Case 30). (Above, left) Fingertip defect accompanying the distal phalanx, radial articular surface, radial collateral ligament, nail, and pulp defect of > 50% of the fingertip in the nondominant right thumb, group 4 defect. (Above, right) Intraoperative harvesting of the composite flap, including all tissue deficiencies from the nondominant left great-toe. (Below, left) At 1-year follow-up, the composite flap was well-adapted to the right thumb, flap sensory recovery was good, only light touch sensation was reduced, significant upper extremity disability was not observed, finger pinch strength was within normal limits, and patients and observers were very satisfied with the cosmetic outcomes of the fingertip and nail. (Below, right) At 1-year view donor area, finger contour was preserved and significant limitation in the donor foot was not observed.

Free flaps without glabrous tissue provide adequate fullness and sensory components but cause pulp enlargement, shearing problems under mechanical stress, and inadequate bone and nail transfer in composite defects.[6,14,18,27] Free flaps from the palmar and plantar glabrous tissues have been used for pulp reconstruction to solve these problems. Hypothenar perforator-based free flaps (HPFF) provide esthetic and functionally satisfactory results.[28,29] For similar advantages, the medial plantar artery-based perforator free flap (MPAP) is used for fingertip reconstruction.[30,31] However, these flaps do not present normal sensory recovery and are insufficient for single-stage reconstruction of composite defects.[14,31]

Free toe flaps provide similar colored and textured glabrous tissue and present good options for fingertip reconstruction.[3-5,13,14,16-19] The second-toe pulp flap presents limited soft tissue without composite contents, insufficient padding for pulp contour, low-caliber neurovascular structures, lower sensorial recovery, skin grafting, and increased complications in large donor defects.[4,5,22,32] This can be an alternative consideration for group 1 and group 2 defects in our classifications.

Free great-toe flaps provide unique coverage and composite tissues, including soft tissue, bone, joints, tendons, and nails, for all fingertip defects through groups 1-4.[3,13,14,18,19] It has a high-caliber neurovascular network that accelerates bone union and wound and nerve healing in the injured area. In our study, even in crush injuries, there were no wound-healing problems; well-sensorial recovery and normal bone union were observed. However, anatomical variations and low-calibrating dorsal veins of the flap have disadvantages.[14,17] Lee et al. used volar veins of the donor finger to avoid venous insufficiency.[4] We observed venous insufficiency and partial flap failure in initial patients but were avoided by incorporating highly calibrated volar and dorsal veins with proximal dissection. In free pulp flaps, short pedicles present fast flap elevation and less donor-site complications but may cause venous insufficiency and flap failure due to anastomosis of small calibration vessels in the trauma zone.[4] Therefore, accessing proximal and highly calibrated veins should not be seen as a disadvantage, given that the mean surgical durations (183.3 ± 55 min) and donor-site complications in our groups were similar to those reported in the literature.[4,13,19,21]

Great-toe flaps have mechanical receptors and textures similar to those of fingertips to render normal sensation and pinching. SWM scores of great-toe flaps were at normal intervals of 2.83-4.74[14,16,18,21] and better than those of second-toe flaps (3.61-5.07).[21,33] In fingertip reconstruction with both nine great-toe and 12 s-toe flaps by Gu et al., sensorial scores were better with great-toe flaps (SWM: 4.02, s2PD: 4.4 mm) than with second-toe flaps (SWM: 4.2, s2PD: 5.08 mm).[21] Similarly, SWM scores were within normal limits (2.83-3.61) in 94% of patients, and only protective touch was decreased (3.84) in 6% of our patients. SWM scores were correlated with s2PD scores (4.09 ± 0.77 mm) in our patients and were better than previous s2PD scores of great-toe flaps (4.44-13.1 mm),[13,14,16,18,19,21] second-toe flap (4.9-8 mm),[4,5,20,21,33] HPFF (4.4-5.7 mm),[28,29,34] and MPAP (4.55-10 mm).[31,35,36] This is attributed to the fact that sensory recovery of the great-toe flap is perfect by high-density cutaneous sensory receptors innervated by the digital nerve and better cortical adaptation.[5,13,14,16-18] Additionally, inclusion of the plantar digital nerve into the flap, tension-free flap adaptation, nerve repair outside the trauma zone, and re-educational sensorial therapy improved the discrimination of our flaps.

Pinching is an important function of the fingertip. Toe fingertip flaps provide well-padded soft tissue and share force power during pinching.[13,14,16] Ten dominant and five nondominant fingertip injuries were reconstructed with great-toe flaps by Lin et al., and their pinch strength scores (5.26 kg) were lower than those of healthy opposite hands (6.03 kg), the scores of five dominant injured hands could not reach healthy nondominant hand scores, but no statistical difference was observed.[16] Similarly, our scores (5.65 ± 1.3 kg) were not statistically different from those of the opposite hand (5.99 ± 1.19), which was attributed to fibrous septal anchoring and better analysis of mechanical stress by high sensorial recovery in great-toe flaps. Our scores were normal in 28 patients, but not in five patients, and it was related to slightly low sensory recovery and decreased response to mechanical stress in these patients.

Esthetic problems of hand cause distress and social withdrawal.[4-6] All tissue defects can be anatomically reconstructed to avoid deformed nails and fingertips. However, the nail, which is the most cosmetic part of the fingertip[7], can only be reconstructed by sharing or moving the nail of another finger. Thus, toe-free flaps are a unique source of nail reconstruction.[13] In our study, nail defects reconstructed by sharing the great-toe nail had overall satisfactory outcomes from all patients.

The most important advantage of free great-toe flaps is the provision of single-stage anatomical reconstruction of composite defects. In addition, free great-toe flaps transfer is an indispensable option for isolated pulp defects because of its excellent results.[14] However, the indications for free great-toe flaps are controversial: only Allen type 2 oblique and more complex defects,[13] complete loss of thumb pulp,[37] loss of two-thirds of the first three fingers' pulp,[20] and social and cultural reasons.[4] However, free great-toe flap is used for defects of the thumb,[18,19,33] thumb and index,[17] and first three[20,21] and four[13,14] fingers. We believe that fingertip reconstruction with great-toe flaps is essential if the remaining local tissue is insufficient for excellent esthetic, functional, and sensorial results.

Our study evaluated reconstruction results with objective and subjective criteria, but it has some limitations, such as a few patients in groups, evaluation of different fingers' reconstruction outcomes together, and inclusion of dominant and nondominant hands together. Donor toe limitations and complications seem relatively high but are attributed to comorbidities, such as smoking, and daily life effects, such as gait disturbance or pain.

Conclusion

We aimed to develop an easy and clinically applicable categorization of fingertip defects according to their characteristics and algorithmic reconstruction using free lateral great-toe flaps; when the dimensions and composite tissue involvements of defects increased, complex surgical skills were required, duration of surgery was extended, return-to-work was delayed, and donor-site complications increased.

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Ethical approval

All study participants provided informed consent, and the study design was approved by the appropriate ethics review board from the Bezmialem Vakıf University Non-Interventional Research Ethics Committee (ethics number: 2021/325).

Disclosure

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Conflicts of interest

There are no conflicts of interest to declare.

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