



Workhorse flaps for distal digital reconstruction: an algorithmic approach to surgical decision-making

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Abstract

Background Owing to its intricate structural and functional anatomy, the fingertip is immensely critical for a wide range of functions like sensation, gripping and fine handling. Therefore, it is important to be familiar with such injuries and their available treatment plans to ensure satisfactory aesthetic and functional results. We present our experience on fingertip reconstruction along with a critical analysis of the employed reconstructive techniques, their outcomes and an algorithm-based approach to address fingertip injuries.

Methods A retrospective chart review of all fingertip injuries presented to the Sawai Man Singh Hospital was conducted during September 2018 and September 2020. Data on the defects size, type of reconstructive technique employed, surgical outcomes and surgical complications was recorded and analyzed.

Results This study included 92 fingertip injuries in 80 participants, 22 injured thumbs, 21 injured index fingers, 24 injured middle fingers, 20 injured ring fingers and 5 injured little fingers were reported. The most common mechanism of injury was machine injury (n = 58, 72.5%) and electric burn (n = 12, 15%). The most common surgical techniques were the V–Y advancement flap (n = 30), Moberg flap (n = 10), reverse homodigital island flap (n = 8) and first dorsal metacarpal artery flap (n = 8). The average size of soft tissue defect was 2.1 cm.

Conclusions Adequate knowledge of the anatomical structures, a satisfactory analysis of the type and mechanism of injury aid in the selection of reconstructive alternatives for fingertip injury, which, in turn, prevents secondary deformities, improves functional outcomes and decreases secondary reconstructive procedures that are more complicated and have unpredictable results.

Level of evidence: Level IV, therapeutic study.

Keywords [MeSH] Finger injuries · Surgical flaps · Thumb · Soft tissue injuries · Reconstructive surgical procedures

Introduction

Fingertip injuries have been described as one of the most commonly occurring injuries of the hand [1, 2]. According to U.S. Census data on the National Electronic Injury Surveillance System database, an estimate of 464,026 patients sustained finger amputations in the USA from 1997 to

2016, resulting in an estimated finger injury incidence of 7.5/100,000 people per year [3].

Although it is highly favourable to address these injuries with replantation, it cannot always be a viable option owing to factors like the mechanism of injury, the condition of the amputated part, ischemia time, the availability of trained professionals and an adequate healthcare setting [4]. In this context, a local flap for fingertip reconstruction can be a very reliable method, as it involves restoration of the padding of the finger to ensure good functional and aesthetically acceptable results. Nonetheless, other techniques such as skin grafting, primary closure and healing by secondary intention can be considered depending on the patient (hand dominance, history of previous injuries, age, smoking and comorbidities) and surgeon-related factors (experience, availability of resources).

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Owing to its intricate structural and functional anatomy, the fingertip is immensely critical for a wide range of functions like sensation, gripping and fine handling. This therefore highlights the importance of being familiar with such injuries and their available treatment plans to ensure satisfactory aesthetic and functional results. Herein, the aim of this study was to present our experience on fingertip reconstruction along with a critical analysis of the employed reconstructive techniques and an algorithm-based approach to address distal digital injuries.

Materials and methods

This study was approved by the institutional review board (IRB) of the Sawai Man Singh Hospital. Informed consent of all the patients was obtained. During October 2020, a retrospective chart review from September 2018 to September 2020 was accomplished of all fingertip injuries presenting to Sawai Man Singh Hospital.

The patient's age and sex, the involved finger, involvement of the dominant or non-dominant hand and the etiology of the lesion were recorded as demographic and clinical variables. Injuries were classified based on the defect size and the type of reconstructive technique employed. Assessment of postoperative outcomes included sensation at 6 months postoperative, tenderness, curving of the nail (for volar defects), coldness, average range of flexion of the thumb, range of motion (ROM) during flexion and extension of the finger and complications. Sensation was evaluated using a grading scale in which a static two-point discrimination at ≥ 6 mm was poor, 5 mm was satisfactory, 4 mm was good and ≤ 3 mm was very good.

Statistical analysis was performed by means of Jamovi 1.2.27.0 (Jamovi, Sydney, Australia). Values were expressed as mean \pm standard deviation (SD). The chi-square test was used to compare the incidence of flap necrosis using different flaps [5]. The comparison of the mean diameter of defects for which each flap was used was performed using the Kruskal–Wallis one-way ANOVA on ranks with the Dwass-Steel-Critchlow-Fligner method for pairwise multiple comparisons [6, 7].

Results

During a period of 25 months between September 2018 and September 2020, 92 fingertip injuries in 80 patients were retrospectively recorded by means of the medical record of Sawai Man Singh Hospital. This study included a total of 80 participants, 45 males (56.3%). The mean age was 38.5 ± 15.9 years. Injuries occurred in the dominant hand in 55% ($n=44$) of the cases (Table 1). A single-digit injury

Table 1 Demographic and clinical characteristics of included patients

	Frequency	Percent
Number of patients	80	100%
Male	45	56.30%
Female	35	43.80%
Age (mean)	38.5 ± 15.9	Range, 12–76
Injured hand		
Dominant hand	44	55%
Non-dominant hand	36	45%
Injured fingers	92	100%
Thumb	22	23.80%
Index	21	22.80%
Middle	24	26.00%
Ring	20	21.70%
Little	5	5.40%

occurred in 90% of the cases, double digit in 6.25%, triple digit in 2.5% and quadruplet digit injury in 1.25%. The mechanism of injury was machine injury ($n=58$, 72.5%), electric burn ($n=12$, 15%), deformity secondary to infection ($n=4$, 5%), trauma/crush ($n=2$, 2.5%), trauma/fall ($n=1$, 1.25%), road-traffic accident ($n=1$, 1.25%), failed FDMA flap secondary to electric burn ($n=1$, 1.25%) and non-specific trauma ($n=1$, 1.25%).

The V–Y advancement flap was the most common surgical technique for fingertip reconstruction, employed in 32.6% ($n=30$) of the cases. Among other reconstructive alternatives we employed the Moberg flaps in 10.9% ($n=10$) of the cases, the reverse homodigital island flap (RHIF) in 8.7% ($n=8$), the first dorsal metacarpal artery (FDMA) flap in 8.7% ($n=8$), the Littler flap in 7.6% ($n=7$), the Segmuller-Venkataswami flap in 6.5% ($n=6$), the Kutler flap in 5.4% ($n=5$), the cross-finger flap in 5.4% ($n=5$), a full-thickness skin graft (FTSG) in 4.3% ($n=4$), the thenar flap in 4.3% ($n=4$), the reverse radial forearm flap (RRFF) in 3% ($n=3$) and primary closure in 2.2% ($n=2$).

The average diameter of defects for which each reconstructive technique was used is presented in Table 2. A significant difference was found between the average diameter of defects for which each reconstructive technique was used ($df, 11; \epsilon^2=0.694; p<0.001$). The volar V–Y advancement flap was significantly more frequently used for smaller defects compared to the cross-finger flap ($p=0.019$), FDMA flap ($p<0.001$), Segmuller-Venkataswami flap and RHIF ($p=0.005$). No other significant difference was found during pairwise comparison analysis.

Results of static two-point discrimination test following reconstruction with the different flap techniques are exhibited in Fig. 1. The most outstanding results were observed with the V–Y advancement flap, the Moberg flap, the Kutler flap and the Segmuller-Venkataswami flap in which 86.7%,

Table 2 Average diameter of soft tissue defects for which each reconstructive technique was used and postoperative tenderness, curving of the nail and sensation of coldness following fingertip reconstruction

Type of reconstruction	Diameter ± SD (cm)	Tenderness (%)	Curving of nail-volar defects (%)	Coldness (%)
V–Y flap	1.6 ± 0.2	30	25	50
Littler flap	2.7 ± 0.6	32	NR	30
Moberg flap	1.9 ± 0.3	20	35	40
Cross-finger flap	2.6 ± 0.4	10	NR	NR
Reverse homodigital island flap	2.1 ± 0.3	40	NR	20
Full-thickness skin graft	2.4 ± 0.5	NR	NR	NR
Kutler flap	1.5 ± 0.2	62	30	60
Reverse radial forearm flap	3.3 ± 0.6	NR	NR	NR
First dorsal metacarpal artery flap	2.5 ± 0.3	22	NR	20
Thenar flap	1.7 ± 0.4	NR	NR	NR
Primary closure	1	NR	NR	NR
Segmuller-Venkataswami flap	2.5 ± 0.3	NR	NR	33

Abbreviation: *NR*, not reported

Results of Static Two-point Discrimination

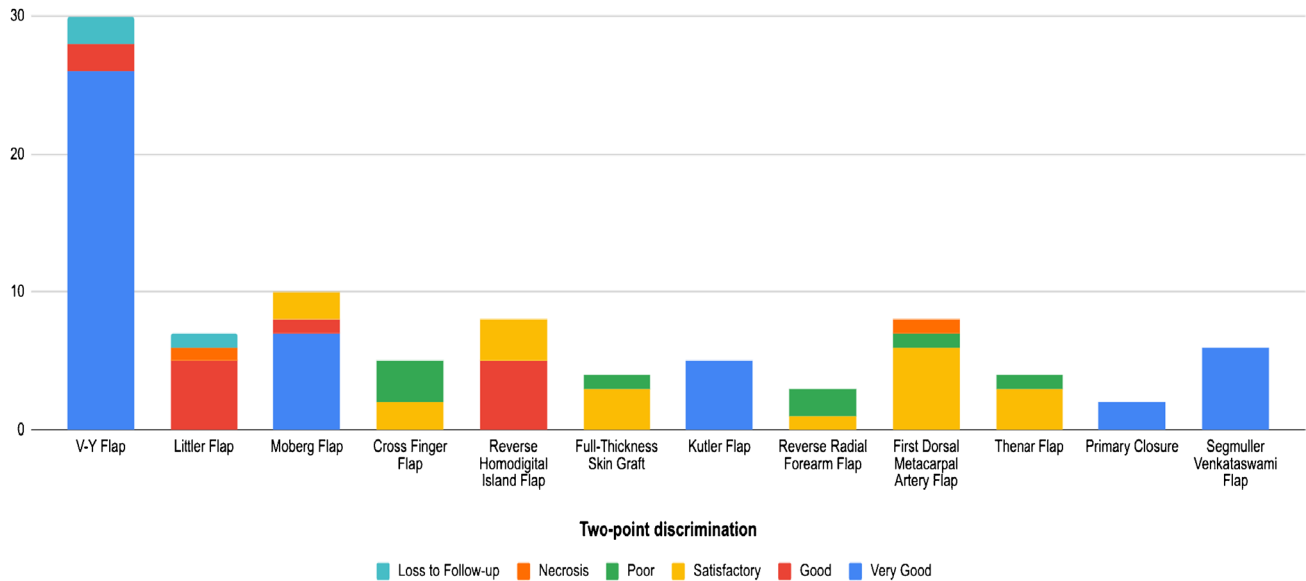


Fig. 1 Results of status 2-point discrimination exhibited for the different surgical techniques

70%, 100% and 100% of patients achieved a very good (< 3 mm) static 2-point discrimination, respectively.

Tenderness after reconstruction was present in 30% of the cases treated with a V–Y advancement flap, 20% with the Moberg flap, 32% in cases managed with the Littler flap, 62% with a Kutler flap, 40% with a RHIF, 22% with a FDMA flap and 10% with a cross-finger flap. Curving of the fingernail occurred in 25% of patients treated with a volar V–Y advancement flap, 35% with a Moberg flap and 30% with a Kutler flap. Fifty percent of patients reconstructed with a V–Y advancement flap experienced coldness, 40%

with a Moberg flap, 30% with Littler flap, 60% with Kutler flap, 20% with RHIF, 20% with FDMA flap and 33% with the Segmuller-Venkataswami flap (Table 2).

Six surgical complications during the postoperative period were reported. Venous congestion of the flap was reported in 3 patients, one RHIF and two Littler flaps; all resolved uneventfully without requiring further interventions. One patient reconstructed with a FDMA flap presented with an infection during the postoperative period, which was managed with antibiotics. The flap failure rate was not significant among the different reconstructive techniques (df,

11; $p=0.482$). Flap failure occurred in two cases (2.17%), one Littler flap and one FDMA flap. Coverage of the soft tissue defect was performed using a cross-finger flap in both cases.

Our study demonstrated that reconstruction using V–Y advancement flaps was associated with a good postoperative ROM. On the other hand, the Moberg flap was associated with reduced extension owing to the propensity for flexion contracture at the IP joint. In patients with reconstructive procedures using the cross-finger flap, we observed that there was reduced mobility, perhaps due to the stiffness during immobilization. However, with active physiotherapy, patients were able to achieve a good ROM. Other flaps discussed in the study had an acceptable ROM. All patients in our study were advised to start active physiotherapy which has been shown to yield better results (Table 3).

Discussion

There are several techniques reported to treat fingertip injuries (Supplementary Table 1). In that matter, for a standardized approach regarding the reconstruction of traumatic injuries to the fingers, we have developed an algorithm that may aid the physician to decide the best course of action in almost all levels of hospital care (Fig. 2).

Before a complex and morbid reconstruction is contemplated, healing by secondary intention should be considered as a reconstructive alternative. This method is inexpensive and regarded as an easy fix with excellent reported clinical outcomes [8]; however, it involves a long healing process (2–4 weeks approx.) with unsatisfactory aesthetic results.

For that reason, it is recommended when there is no bone or tendon exposure, and the size is less than 1 cm². Buckley et al. reported 21 fingers in 19 patients managed with healing by secondary intention yielding median time to return to work of 7 days. All patients expressed that they preferred this treatment rather than a terminalization (Fig. 3) [9].

When soft tissue defects extend beyond a 2-cm diameter, skin grafts of different thicknesses can be used. Nonetheless, when tendons or bones are exposed, revascularization is poor and graft take may be compromised. Furthermore, grafts do not offer a stable environment for the tendons to glide thereby reducing the functionality [10]. However, recent studies have shown that full-thickness skin grafts are reliable to use in this context [11]. In this sense, the incorporation of graft can be used in defects of 2 cm, but its use must be thought judiciously as Moynihan stressed that tenderness follows when grafts are placed over bony prominence which can also lead to ulceration and are prone to injury [12, 13].

The majority of fingertip injuries are effectively managed with V–Y advancement as seen in our series [14, 15]. In our experience, the V–Y advancement flap is favourable for resurfacing either transverse, volar or even dorsal defects of the fingertip as highlighted by Lim et al. (Fig. 3) [16]. The advantages of the V–Y advancement flap are the length and sensation preservation, as well as good soft tissue coverage for small defects (1.6 ± 0.2 cm) [17]. Similar to Atasoy et al. who reported normal fingertip sensation in 97% of their patients, in our series 93.3% of patients achieved a 2-point discrimination of ≤ 4 mm following reconstruction [14]. In some cases, tight sutures of the skin to the nail bed can result in hook nail deformity, and hence, this should be avoided

Table 3 Average range of motion postoperative for thumb flexion, index and middle finger flexion and extension following fingertip reconstruction

Flap	Thumb flexion (degrees)	Index finger flexion (degrees)	Ring and middle finger flexion (degrees)	Extension (degrees)
V–Y advancement flap	NR	60	70	7
Moberg flap	70	NR	NR	2
Littler's flap	NR	70	75	
Kutler flap	NR	NR	NR	8
Reverse homodigital island flap (PIP)	NR	65	70	9
Reverse homodigital island flap (DIP)	NR	60	60	9
First dorsal metacarpal artery donor – 2 nd MCP	NR	71	NR	10
First dorsal metacarpal artery 1 st MCP	NR	70	NR	10
First dorsal metacarpal artery (PIP)	NR	65	NR	10
Segmuller-Venkataswami flap (PIP)	NR	60	70	10
Segmuller-Venkataswami flap (DIP)	NR	56	57	10
Cross-finger flap	NR	56	60	11
Reverse radial forearm flap	70	NR	NR	10

Abbreviation: 1st, first; 2nd, second; *MCP*, metacarpophalangeal joint; *PIP*, proximal interphalangeal; *DIP*, distal interphalangeal

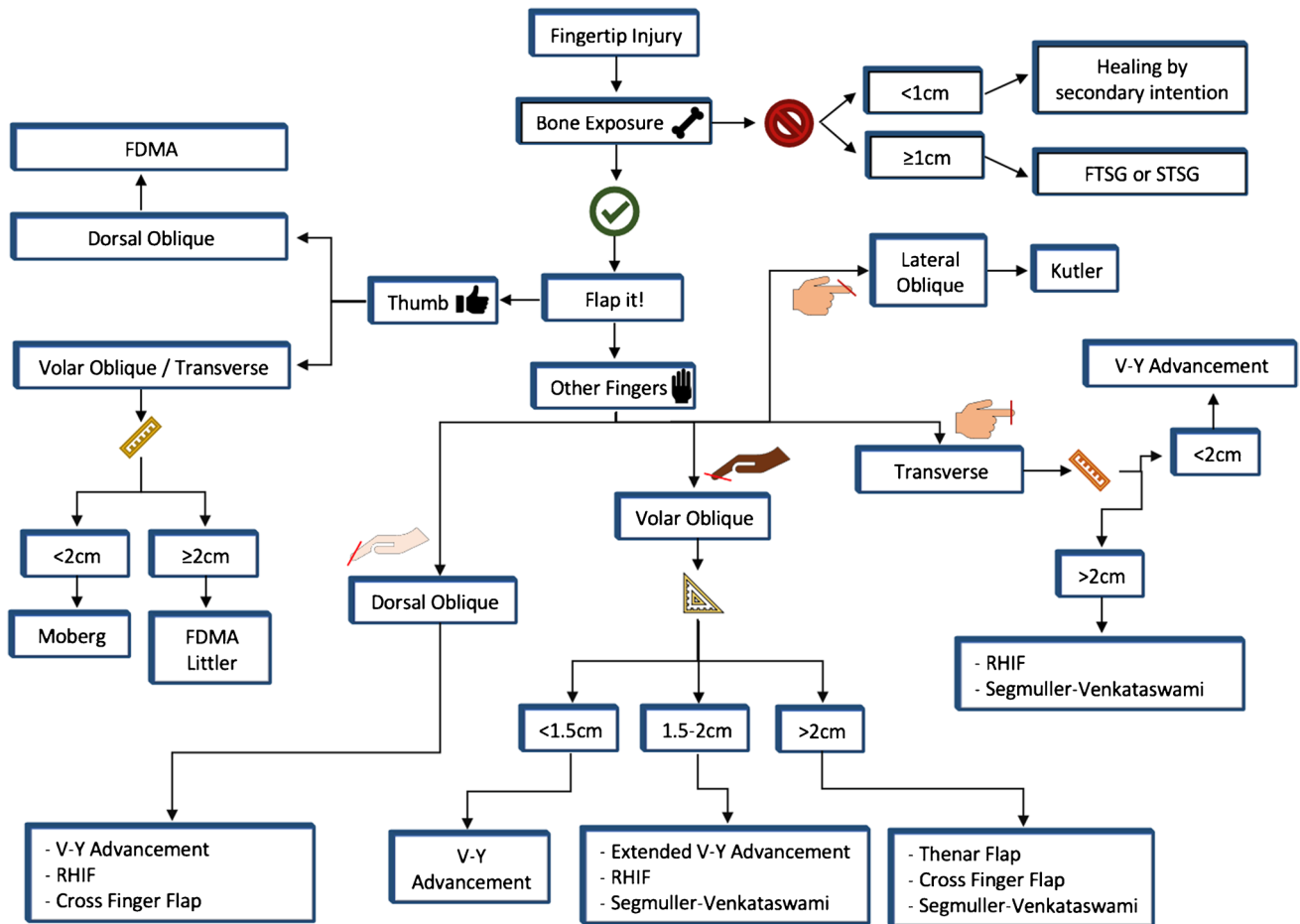


Fig. 2 Algorithm

Fig. 3 Multiple finger amputation. Moberg flap for the thumb, Kutler flap for the index finger, V–Y advancement flap for middle finger and skin graft for the ring finger



[14, 17]. Twenty-four percent of our patients presented with hook nail deformity and 30% displayed varying degrees of tenderness using this technique.

Kutler in 1947, designed a bilateral V–Y flap that successfully provided adequate coverage of moderate fingertip

defects (1.52 cm) and overcame the limitations of the unilateral V–Y flap described by Geissendörfer (Fig. 3) [18, 19], Gaber et al. reported a series of twenty-four patients in which 20 had complete wound healing within two weeks and regained normal function within six weeks (Gaber 1979).

In comparison to our series in which 100% ($n=5$) obtained very good 2-point discrimination and no flap infection or necrosis, eighteen patients in the series described by Gaber et al. experienced variable degrees of hypoesthesia initially, one patient presented with flap necrosis and one patient had a postoperative finger infection [20]. Super Kutler flaps as described by Arpacil et al. making mid-lateral lazy-S incision from the apex point of the triangle to the proximal interphalangeal (PIP) joint crease to expose the neurovascular pedicles can provide coverage of defects of up to 2.2×1.7 cm, in case more extensive defects are presented [21].

Sahu et al. reported a series of 12 patients managed with the thenar flap. The mean time of flap detachment was 17.3 days. Partial flap necrosis occurred in 2 patients which were managed conservatively, and 2 patients developed flexion contracture of the PIP joint [22]. In comparison, all patients who received reconstructive procedures using the thenar flap recovered uneventfully and did not present flap necrosis in our series (Supplementary Fig. 1). The mean static 2-point discrimination reported by Sahu et al. was 6.3 ± 2.2 mm (range, 4–10 mm) at the end of 1 year, while Rinker et al. reported a static 2-point discrimination of 6.8 ± 2.5 (range 3–10) in a cohort of 19 patients [22, 23]. In our series, one and three patients had a poor (> 5 mm) and a satisfactory (5–4 mm) 2-point discrimination, respectively.

Initially described by Gurdin and Pangman, and later modified by Cronin, the cross-finger flap is a very reliable option to address large defects up to 2.6 ± 0.4 as exhibited in the present study [24, 25]. The flap should be designed at the level of the middle phalanx dorsally, from proximal interphalangeal to DIP creases. This facilitates skin grafting as the subcutaneous tissue of the skin of the flap always remains superficial to the paratenon of the extensor mechanism throughout dissection. This will permit proper perfusion initially and at the same time provide a superior outcome owing to the better padding for the reconstructed pulp [24, 25]. Similar to our cohort, Rabarin et al. reported a series of 22 patients who were managed with cross-finger flaps reporting no postoperative complications such as necrosis, infection or wound dehiscence [26].

The Moberg flap is based on the neurovascular bundle of the thumb and is an excellent reconstructive technique to address medium-sized (≤ 2 cm) palmar injuries of the thumb pulp (Fig. 3) [27, 28]. Some modifications have been reported over the years. For instance, O'Brien et al. converted the advancement flap to an island flap to enable coverage of large defect sites [29]. On the other hand, Germann et al. recommended bilateral Z-plasties at the base of the flap along with dividing the subcutaneous septa to minimize the incidence of flexion contractures of the interphalangeal joint [30]. V-Y extensions, burrow triangles and full-thickness skin graft after proximal skin bridge division have been also reported to increase flap mobility [30]. Similar to the

results of Thibaudeau et al., in which all three reconstructed cases displayed static 2-point discrimination of < 6 mm, our study reports static 2-point discrimination within the range of 2–5 mm [31].

Although a Littler's flap is not regarded as the first reconstructive option for many, it is advantageous to cover defects of the thumb when the donor site is at risk of further complication due to the extensive flap dimension required for coverage (≥ 2 cm). The flap is usually harvested from the ulnar aspect of the middle or the ring finger as this reduces the possibility of donor site morbidity (Fig. 4) [32–34]. In our series, all the reconstruction in which Littler's flap was incorporated, the 2-point discrimination was good. Interestingly, Chen et al. reported that the mean static 2-point discrimination of the Littler flaps was 7.6 mm (range, 5–12 mm) compared to 9.3 mm (range, 6–13 mm) of bipediced nerve flaps [35].

In our series, two Littler flaps suffered from venous congestion during the postoperative period and another flap was lost due to necrosis. This was attributed to the long course of dissection around the flap that increases the chances of injury to the venous supply, and ultimately, the risk of venous congestion postoperatively [32–34]. However, Wang et al. and Cheng and colleagues reported a 100% survival rate in their cohort, which advocates for this flap as a reliable alternative [35, 36].

In our experience, the FDMA flap is favourable in the reconstruction of proximal and distal phalanx defects and thumb defects measuring > 1.5 cm as highlighted by Muyltermans and Foucher, respectively [37]. The greatest advantage of employing this flap to reconstruct the thumb is that it is ideally a self-sufficient flap that provides a vascularized, sensate skin to cover the defect making it possible to claim superior reconstructive outcomes (Fig. 5) [38]. Unlike Shun-Cheng et al. who reported 2-point discrimination of 8.1 mm, 87.5% of our patients treated with FDMA reported average 2-point discrimination of 5.1 mm [39]. Also, in our study, two patients treated with FDMA had complications in the form of infection and necrosis; the former healed with antibiotics, whereas the latter required further reconstruction using cross-finger flaps.

The RRF, described as a “reconstructive chameleon” due to its versatile properties, can be used for extensive fingertip defects of up to 3.3 ± 0.6 (Fig. 6) [40–42]. The flap harvest is relatively straightforward owing to its predictable anatomy, but it is important to be careful and preserve the perforators located proximally deep in the septum between the brachioradialis and flexor carpi radialis (FCR). A proximal incision is helpful in isolating the radial artery and its venae comitantes. A tunnel creation facilitates the transfer of the flap to the defect site. A small graft may be needed to cover the pedicle if there is too much tension on the skin [40]. To prevent donor site morbidity, primary closure is



Fig. 4 Littler flap



Fig. 5 First dorsal metacarpal flap



Fig. 6 Reverse radial forearm artery forearm

advised if the width of the skin paddle is 3–4 cm. Alternatively, a skin graft can also be applied to cover the donor site.

Described by Lai et al. as the reverse digital artery flap and by Kojima et al. as a reverse vascular pedicle digital island flap [43, 44], a flap using a retrograde digital artery has been recognized universally due to its versatility (Fig. 7). However, the patency of both digital arteries along with a patent middle transverse anastomotic at the level of the neck of the middle phalanx over the C3 pulley that provides the retrograde perfusion for the flap is critical for a successful reconstruction [43, 44]. This enables it to cover large defects (even complete amputations) irrespective of their obliquity (dorsal or volar) [43, 45].

The only major limitation of this flap is its technically demanding surgical process and associated postoperative venous congestion as it occurred with one patient in our series so tight skin closure must be avoided [44]. The risk of flap necrosis is always present. Karacalar et al. reported a series of 19 patients who had homodigital reverse vascular and neurovascular island flaps; venous congestion

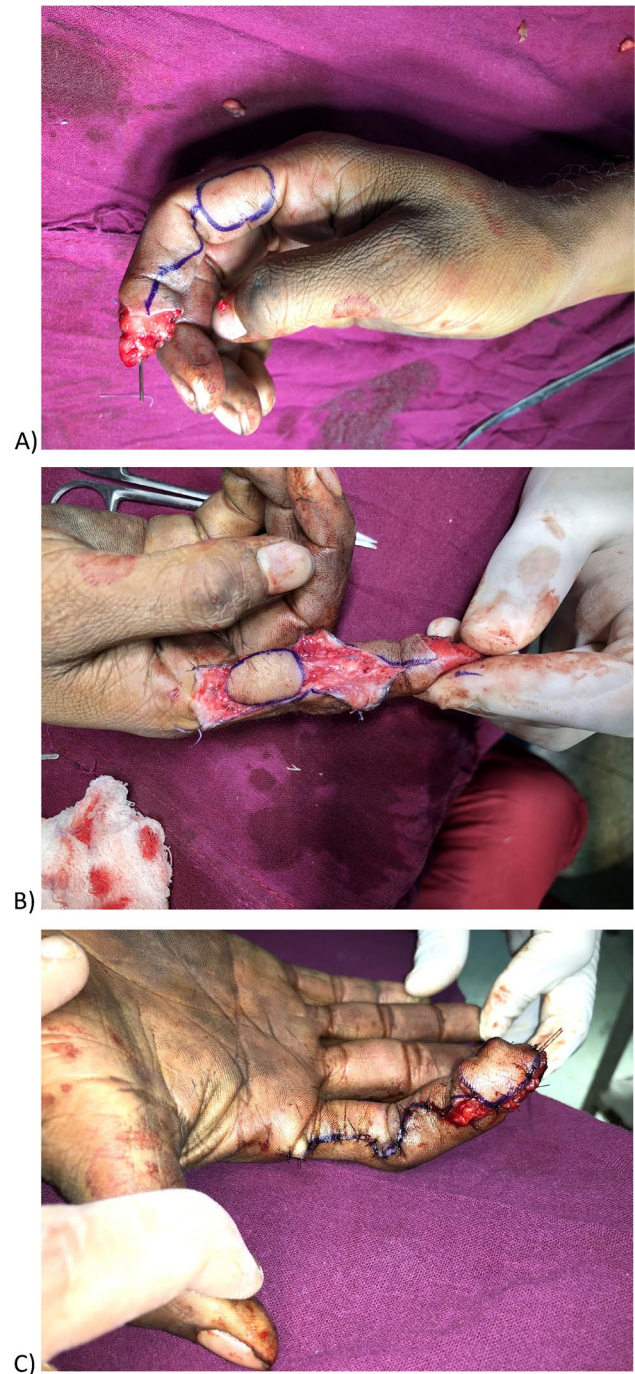


Fig. 7 Reverse homodigital artery island flap

was associated with complete necrosis in 2 patients [46]. Nonetheless, similar to our results, in which 100% flaps survived, Lai et al. reported a series of 11 patients reconstructed with this technique and no case of flap necrosis. Yazar et al. reported 70 fingers of 66 patients reconstructed with the RHIF yielding a normal (<6 mm) static 2-PD in 40 fingers and fair (6–10 mm) in 30 fingers. Comparably, 62.5% and 37.5% of the patients reconstructed with the RHIF in our

series had a good and satisfactory 2-point discrimination outcome respectively [47].

Conclusions

Fingertip defects require a precise and deep understanding of the intricate anatomy of digits. We have demonstrated that a few workhorse flaps when used judiciously after understanding the nature of the defect give excellent functional outcomes and predictable results. Our algorithm aids in decision-making while addressing these types of defects.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s00238-021-01840-2>.

Declarations

Ethics approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. This is a retrospective study. The institutional ethics committee has confirmed that no ethical approval is required.

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

Patient consent Patients signed informed consent regarding publishing their data and photographs.

Conflict of interest The authors declare no competing interests.

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