Soft Tissue Cover of the Hand

6

Steven Lo and Mark Pickford

Keywords
Soft tissue cover hand • Current evidence • Comparative studies • Small free flaps • Flaps

Part 1. Non-flap Based Approaches to Soft Tissue Cover

Non-flap based approaches to fingertip reconstruction are often equal in many aspects to more complex flap reconstructions, and in some areas may in fact be superior.

Healing by Secondary Intention

A review of the use of semi-occlusive dressings found compete wound healing in all cases, with an average 2PD of 3.6 mm, sufficient for the recovery of tactile gnosis [1]. A study comparing a number of different methods of fingertip reconstruction found in favour of using dressings alone, particularly in terms of recovery of excellent 2PD of 3.8 mm and earlier return to work than other methods. Drawbacks of using dressings alone include the poor quality padding of the fingertip, as indicated by a relatively high scar sensitivity of 54 % [2].

Skin Grafts

Lister has recommended using FTSG on the functional side of the finger, to provide more robust cover and using SSG on the non-functional side to allow the wound to contract, thereby pulling in sensate, good quality skin from the surrounding tissue [3]. However, grafts should be used sparingly for fingertip reconstruction, as prospective reviews indicate that both split and full thickness skin grafts perform poorly in comparison to simple flaps, in terms of 2PD and scar sensitivity [2].

Composite Grafts

There are conflicting reports regarding the overall success rates and variables that affect success in composite grafts. One study has suggested that composite grafts are more likely to be successful if performed within 5 h. However, the outcomes

S. Lo, MA, MSc, FRCS Plast (✉)
Canniesburn Plastic Surgery Unit,
Glasgow Royal Infirmary, Glasgow, UK
e-mail: stevenjlo@gmail.com

M. Pickford, FRCS Plast
Department of Plastic Surgery,
Queen Victoria Hospital, East Grinstead, UK
e-mail: mark.pickford@qvh.nhs.uk

I.A. Trail, A.N.M. Fleming (eds.), *Disorders of the Hand: Volume 1: Hand Injuries*,
DOI 10.1007/978-1-4471-6554-5_6, © Springer-Verlag London 2015

in this study were based on parental questionnaire rather than clinical review, and the conclusions should therefore be interpreted with caution [4]. Other variables that have been correlated with composite graft failure include smoking and composite grafts proximal to the eponychial fold [5]. Given the conflicting evidence and lack of high-level evidence available, we consider composite grafts as non-urgent and indicated primarily in children. As simple flap reconstruction can provide near normal 2PD and rapid primary healing, one must carefully consider whether a composite graft is the most appropriate method in adults.

Part 2. Flap Cover of the Digits

Background

Functional Considerations

The fingertip is defined as the portion of finger beyond the insertion of the extensor and flexor tendons, but is often inaccurately described as the portion distal to the DIPJ. In terms of restoration of useful function to the hand, flap reconstruction is most relevant for amputations at the fingertip level. In amputations proximal to the fingertip and DIPJ crease, complex flap reconstruction does not result in significant functional gain. If one considers Swanson's classification of hand impairment, 50 % of the function of a digit is lost when the finger is amputated distal to the DIPJ [6]. It is therefore justifiable to preserve length in fingertip amputations, but once one has lost finger length proximal to the DIPJ, the benefit to preserving length is largely lost, and one would be better to consider revision amputation rather than flap reconstruction.

Sensory Considerations

Tactile gnosis, or the ability of the finger to "see", is one of the unique aspects of sensory restoration in fingertips, with Moberg showing that a 2PD less than 6 mm is required for normal tactile gnosis [7–9]. Although some have questioned the reliability of 2PD in isolation as a test for tactile gnosis, it remains one of the universal outcomes recorded in most studies [10]. That being said, tactile gnosis is more critical in the functional surfaces of a fingertip (ulnar thumb, radial index, radial middle and ulnar little in particular). In comparison, non-functional surfaces may be adequately resurfaced with methods that do not restore tactile gnosis (such as flaps with a 2PD >6 mm) without significant disability. Furthermore, less emphasis should be placed on 2PD with heterotopic flaps, due to problems with the dual location phenomenon. In such circumstances it is more important that attempts are made to circumvent the dual location phenomenon, rather than concentrate on restoration of 2PD. Additionally, 2PD cannot be considered in isolation without considering scar sensitivity. It is essential to avoid placing scars on the functional surfaces of the fingertips if possible, otherwise the reconstructed digit will be simply "bypassed".

Classifications

There are a number of classifications in use for fingertip injuries. Two variables are involved – firstly, length of amputation for which we use Ishikawa's classification (Fig. 6.1), and secondly, angle of amputation [11]. The angle of amputation may be referred to as volar oblique (or volar facing), dorsal oblique, transverse, radial and ulnar oblique.

Soft Tissue Cover of the Fingertips (Index to Little)

Surgical Techniques

For the purposes of this chapter, reconstructive options have been divided into those for the fingertip proper, dorsum of finger and volar surface of finger. The techniques are subsequently divided into homodigital, heterodigital, distant pedicled and free flaps. We cover each area in turn, but will address free flap reconstruction of the digits in a later section.

Homodigital Flaps

Options

I. VY Advancement
II. Hatchet Flap
III. Bilateral Lateral VY Flaps (Kutler/Segmuller flaps)

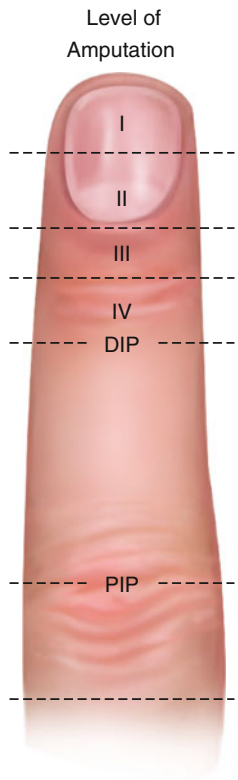


Fig. 6.1 Ishikawa levels of amputation

IV. Triangular Homodigital Advancement Flaps (Venkatswami flaps)
V. Reverse Homodigital Flaps

VY Advancement Flaps

Indications

Dorsal oblique and transverse amputations [3]. Amputation level up to midnail (Ishikawa I) for standard VY, or up to eponychial fold (Ishikawa II) for modified bipedicled VY

Technique and Refinements

Variations of VY advancement flaps have been described since 1935, but were popularized by Atasoy in 1970 [12, 13]. More recently, the VY flap has been modified as a neurovascular bipedicled flap, taken proximal to the DIPJ crease where the neurovascular bundles are more defined [14]. This allows advancement of up to 14 mm [15].

Limitations

Limited movement with standard VY

Advantages

Simple, good 2PD and aesthetics.

Outcomes

Lorea looked at 22 neurovascular VY advancement flaps, finding a static 2PD of 6 mm, 2 infections, 1 neuroma and 1 PIPJ flexion contracture [15]. Elliot reviewed 102 flaps, 46 original VY and 56 neurovascular VY. Cold intolerance was 13 % in both groups, and hypersensitivity noted in 14 % again in both groups. 2PD is not discussed in this paper [14]. In Ma et al. prospective comparative review of fingertip flaps, the VY flap fared well against other flaps in terms of scar sensitivity and 2PD of 4.3 mm [2].

Hatchet Flap

Indications

Ulnar or radial oblique, dorsal oblique, and transverse amputations. Particularly useful in resurfacing the functional surfaces of the index or little fingers.

Technique and Refinements

The hatchet flap is a rotation advancement flap initially described by Emmett for sites other than the fingertip, such as ischial and trochanteric pressure sores [16]. It has also been described for resurfacing small defects of the fingertip pulp [17]. In essence it is designed as a volar VY flap with three quarters of one side of the V left intact, on which the flap rotates and advances (Fig. 6.2). By placing the base of the flap on the functional surface of the finger, it obviates the problems of scar sensitivity. It is therefore an excellent option for preserving the functional borders of the index and little fingers.

Limitations

Limited amount of flap advancement

Advantages

Avoids placing scar on functional surface of digit

Fig. 6.2 Hatchet flap. (**a**) Transverse amputation middle finger. (**b**) Design of hatchet flap so that base is on the functional side of the middle finger (radial). (**c**) Flap rotates and advances. (**d**) Finger seen from the radial side – no scars are placed on this functional surface

Outcomes

Tuncali et al. described its use in 19 cases of fingertip injuries, with a 1 year follow up showing a 2PD of 6.3 mm, cold intolerance in 22 % and return to work in 5 weeks [17].

Bilateral Lateral VY Flaps (Kutler and Segmuller Flaps)

Indications

Subtotal finger pulp amputations

Technique and Refinements

The lateral VY flap was originally described by Geissendorfer in 1943, and later described in its bilateral form by Kutler [18, 19]. In its original form it was raised without isolating the neurovascular pedicle. This was subsequently modified by Segmuller and others by dissecting out the neurovascular pedicle, thus allowing greater flap advancement, and by raising it proximal to the distal phalanx [20, 21]. Some authors have extended as far as the proximal phalanx [22]. Although Kutler and Segmuller flaps are generally bilateral, it can also be used as a unilateral flap, more akin to a short Venkatswami flap, in order to avoid copious scarring of the volar finger. However, unlike the Venkatswami flap, the Segmuller flap does not cross the volar midline of the finger.

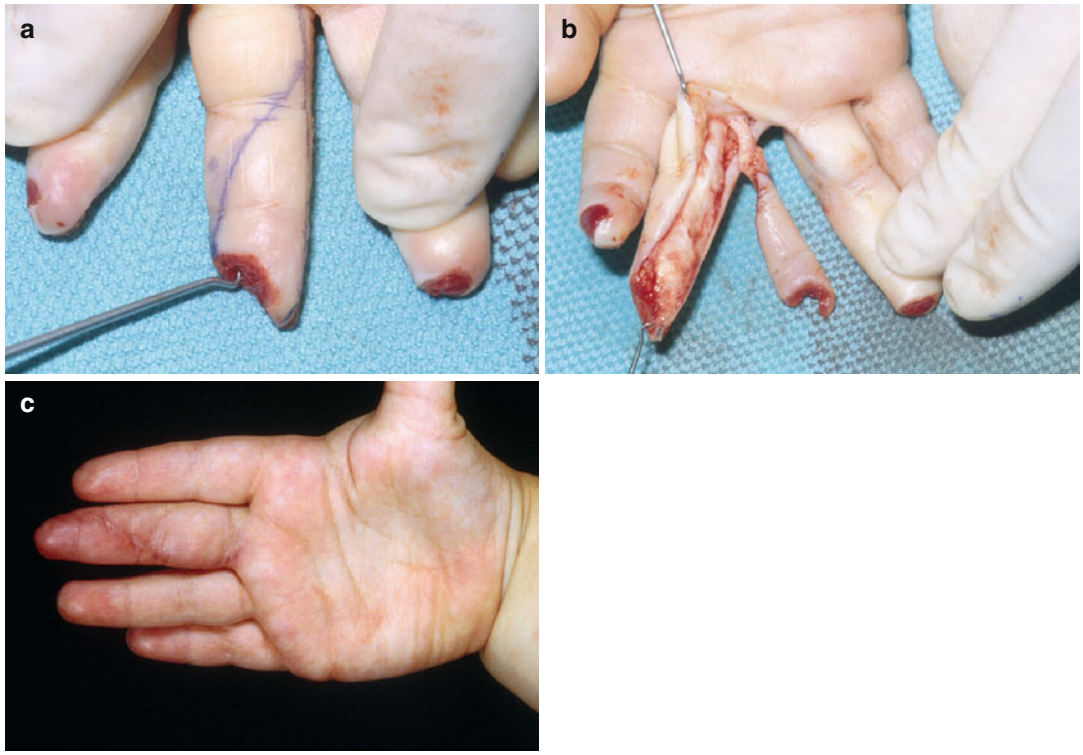


Fig. 6.3 Venkatswami flap. (**a**) Flap design, extended to base of finger. (**b**) Flap pedicle raised with adipose cuff. (**c**) Final result with no flexion contracture

Limitations

Kutler flap (unmodified) has relatively poor outcomes in comparison with other flaps. Places extensive scarring on the fingertip producing scar sensitivity and also DIPJ stiffness [2].

Advantages

Modified neurovascular pedicled flap is more versatile. Can raise one before assessing need for second flap. Both flaps retain innervation unlike the contralateral tip of the Venkatswami flap. Reliable.

Outcomes

Smith and Elliot reviewed 100 cases of the extended Segmuller flap, with 1 partial flap necrosis and 5 neuromas. Forty-five percent cases had normal static 2PD [22]

Homodigital Triangular Advancement Island Flaps (Venkatswami)

Indications

Volar or dorsal oblique laceration <2 cm.

Technique and Refinements

Described by Venkatswami in 1980, the homodigital triangular advancement flap has not found universal favour amongst hand surgeons due to perceived problems with flexion contractures (Fig. 6.3) [23]. The step-advancement modification by Evans and Martin in 1988 provides a logical solution, although formal outcomes have not been independently reported [24]. However, we have not found problems with flexion contracture when the flap is islanded completely and appropriate post-op therapy is instituted.

Neither have we found any great advantages to using the step-advancement flap, which additionally has no scope for maneuver once raised.

Limitations
Flexion contracture if night extension splint not used.

Advantages
Excellent 2 PD allows regain of tactile gnosis

Outcomes
Lanzetta reviewed 25 cases and found 1 case of necrosis, no neuroma, stable padding, hypersensitive scar in 12 %, cold intolerance in 80 % and extension lag in 7 cases (28 %) of 10–45° [21]. None of the patients with extension lag wore night extension splints as instructed, with no lag in patients who used the night splint. 2PD was 3–6 mm and in 92 % cases was equivalent to contralateral digit.

Reverse Homodigital Flap

Indication
Large volar oblique defects or total pulp loss.

Technique and Refinements
First described by a number of authors including Lai in 1989 [25]. This is a reverse flow flap raised at level of proximal phalanx, with or without the dorsal branch of the digital nerve, with a pivot point 5 mm proximal to the DIPJ where the check rein anastamosis enters the digital artery. There is conflicting evidence whether coaptation of the dorsal digital branch improves 2PD [26, 27]. However, digital nerve coaptation may have advantages in terms of cortical perception, as it may prevent the dual location phenomenon. Venous congestion can be a problem if the flap pedicle is skeletalised, but one can easily keep an adipose cuff, or alternatively preserve a volar vein with the flap.

Limitations
2PD insufficient for tactile gnosis. Tedious dissection

Advantages
Keeps donor site within injured finger

Outcomes
Yazar reviewd 64 cases and found a 2PD 5.7 mm (coaptation used in all cases), 1/64 partial flap necrosis, 3/64 flexion contracture and 2/64 neuromas [28] (Fig. 6.4).

Heterodigital Flaps

Options
I. Cross Finger Flap
II. Heterodigital Neurovascular island flaps (see later under Littler flap)

Cross Finger Flap

Indications
Subtotal pulp loss, dorsal finger defects (reverse cross finger)

Technique and Refinements
First described by Gurdin and Paganin 1950, the original description described both distally based and laterally based flaps [29]. It is more commonly performed as a laterally based fasciocutaneous flap, with care to preserve paratenon on the extensor tendon for grafting. The pedicle is traditionally divided at 14–21 days, although some authors advocate earlier division [30]. The "innervated cross finger flap" is a variation which additionally takes the dorsal branch of the digital nerve for co-aptation, with one study of 15 patients finding a static 2PD of 3.6 mm (compared with 6–8 mm for traditional cross finger) [31]. The "reverse" cross finger flap is essentially an adipofascial flap for dorsal rather than volar defects [32]. An extended reverse cross finger flap can be used for more extensive defects (Fig. 6.5).

Limitations
Donor finger morbidity, see outcomes section later.

Advantages
Can provide large size flap for subtotal pulp amputations.

Fig. 6.4 Reverse Homodigital. (**a**) Defect. (**b**) Flap designed on lateral aspect P1, dorsal branch digital nerve can be included. (**c**) Digital nerve left in-situ. (**d**) Flap pedicle raised with adipose cuff. (**e**) Flap in-situ

Outcomes

Nishikawa et al. looked at 15 patients – cold intolerance in 53 %, discomfort during manual work 50 %. 6/15 patients unable to use in precision tasks and tactile gnosis, all of these were index finger and were "bypassed" [33]. Paterson et al. examined outcomes of the donor finger (rather than the injured finger) in 17 cases, finding 8/17 stiffness, 10/12 cold intolerance, 8/17 altered pigmentation of graft. No statistical difference was found in stiffness between SSG or FTSG [34].

Fig. 6.5 Extended Reverse Cross finger flap: (**a**) Extensive dorsal defect. (**b**) Dermal flap raised. (**c**) Adipofascial flap raised in traditional manner. (**d**) Flap in-situ

Distant Flaps

In single digit reconstruction we opt for free flap transfer in preference to distant pedicled flaps. However, distant pedicled flaps remain our salvage option should a free flap fail, or in instances where patient comorbidity precludes free flap transfer. Options include the thenar flap, groin flap, cross arm and chest flaps.

Soft Tissue Cover of Defects Proximal to the Fingertip

Defects of the finger proximal to the fingertip do not require the specialized characteristics required for finger pulp reconstruction, such as tactile gnosis and cortical re-orientation. These defects are therefore more amenable to microvascular free flap transfer and heterotopic flaps, where restoration of 2PD is not as critical.

Dorsal Injuries

Nailbed Defects

Options

I. Turnover adipofascial
II. Free toenail
III. Reverse homodigital (see earlier)
IV. Reverse cross finger (see earlier)
V. Hatchet advancement flaps (see earlier)

Turnover Adipofascial Flap

Indications

Dorsal nail complex loss. Can be extended to include volar fingertip loss.

Technique and Refinements

The vascular supply comes from the distal dorsal arterial branches that originate just distal to the DIPJ, and that form a vascular network above the

extensor insertion. A base of least 5 mm is therefore preserved at the distal end of the flap, just proximal to the germinal matrix (Fig. 6.6). Some authors describe the use of this flap to resurface the distal fingertip pulp [35].

Limitations

We do not recommend this flap for finger pulp reconstruction as 2PD recovery is poor and there are better options available.

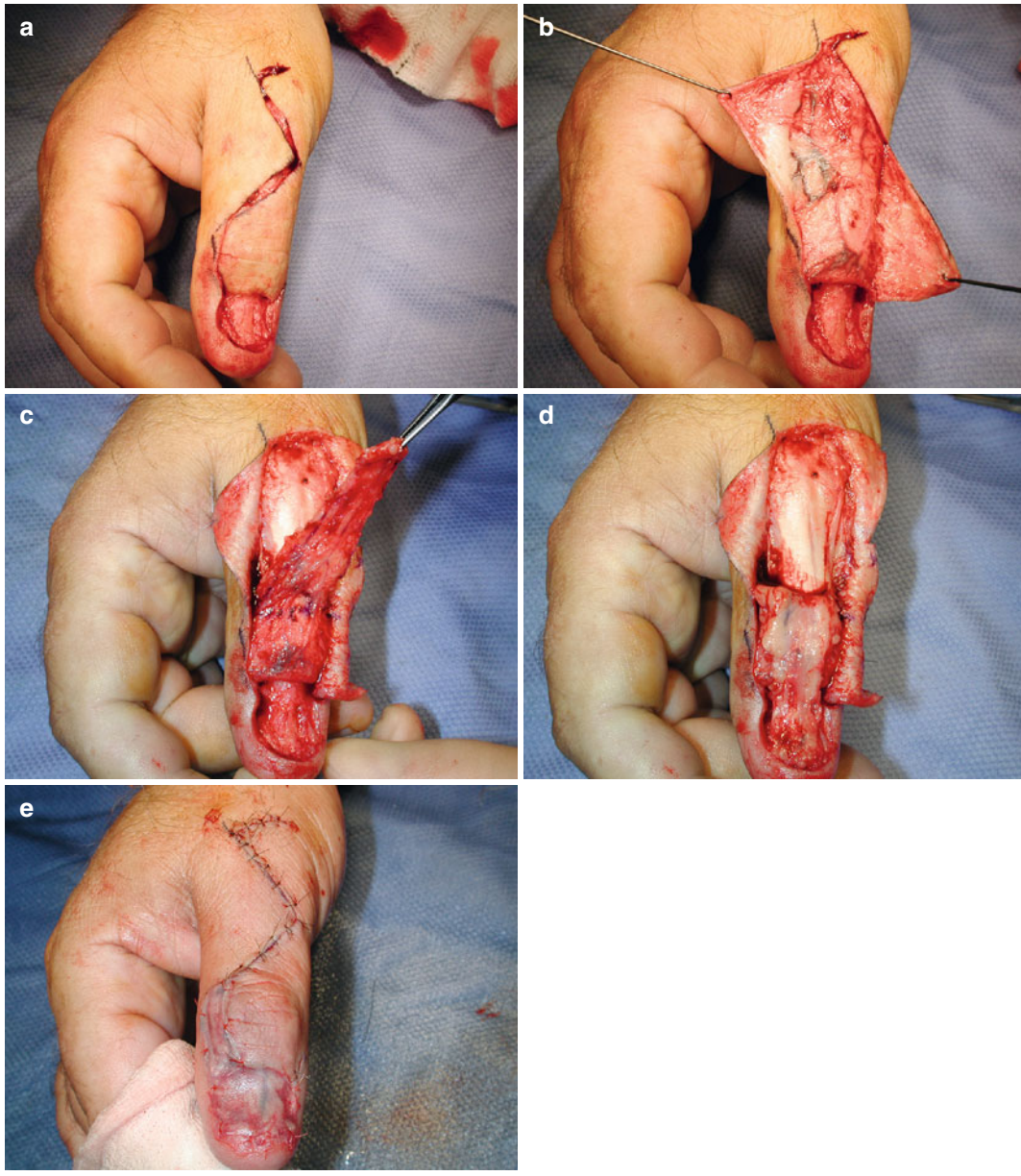


Fig. 6.6 Adipofascial turnover flap (**a**) Defect. (**b**) Flaps raised at dermis-adipose interface. (**c**) Adipofascial flap raised, preserving a base of at least 5 mm proximal to the germinal matrix. (**d**) Turned over. (**e**) Inset and SSG

Advantages
One of the most reliable flaps for nail complex cover

Outcomes
Series of 9 cases with 100 % survival. These were used to cover both the fingertip pulp as well as nail complex, resulting in a 2PD of 8 mm [35].

Microvascular Toenail Transfer

Indications
Nail complex loss for cosmesis or in particular occupations (such as string musicians). Particularly indicated for the thumb [36]

Technique and Refinements
Although toe transfers and variants thereof have existed for many decades, microvascular toenail transfers are comparatively recent [37]. The short pedicle transfer concept is emphasized by some authors, in which a 3 cm pedicle is taken and anastamosed to digital vessels, rather than to the vessels in the anatomical snuffbox [38]. As it is mainly cosmetic in nature, the short pedicle concept helps to minimize donor and recipient dissection and therefore limits cosmetic deformity. Artificial dermis can also minimize deformity of the donor site.

Limitations
Technically demanding, donor site morbidity

Advantages
Excellent cosmesis

Outcomes
Endo et al. described 19 cases of microvascular toenail transfer, with only 1 case of partial necrosis and all achieving normal nail growth. In this series average operating time was 3 h [38]. This compares favourably with non-vascularised toenail grafts, in which only 5 out of a series of 25 achieved acceptable cosmesis [39].

Defects of Dorsal Middle Phalanx

Options
I. Homodigital Adipofascial Turnover Flap (Merle flap)
II. Reverse cross finger (see previous)
III. Venous flow through flap (see later)

Homodigital Adipofascial Turnover Flap (Merle Flap)

Indications
Dorsal defects of the PIPJ and proximal three quarters of the middle phalanx. Extended modification can include up to DIPJ.

Technique and Refinements
Initially described by Voche and Merle in 1994, this flap is an adipofascial flap longitudinally based on one of the digital vessels [40]. There is no secondary defect but the flap itself requires a SSG. The original series described its use for PIPJ defects only, and for dorsal defects of up to two-thirds the width of the finger. More recently, it has been extended to allow flap reconstructions up to the DIPJ and full width of the finger (Fig. 6.7) [41].

Limitations
Flap requires skin grafting

Advantages
Preferred over the reverse cross finger flap as avoids prolonged immobilization and associated stiffness.

Outcomes
Published case series are relatively limited. In the extended Merle flap 3 cases were described with 100 % survival and 1 graft loss [41].

Defects of Dorsal Proximal Phalanx

Options
I. Dorsal Metacarpal Artery Perforator Flaps (Quaba Flap)
II. Venous flow through (see later)
III. Adipofascial turnover (see previous)

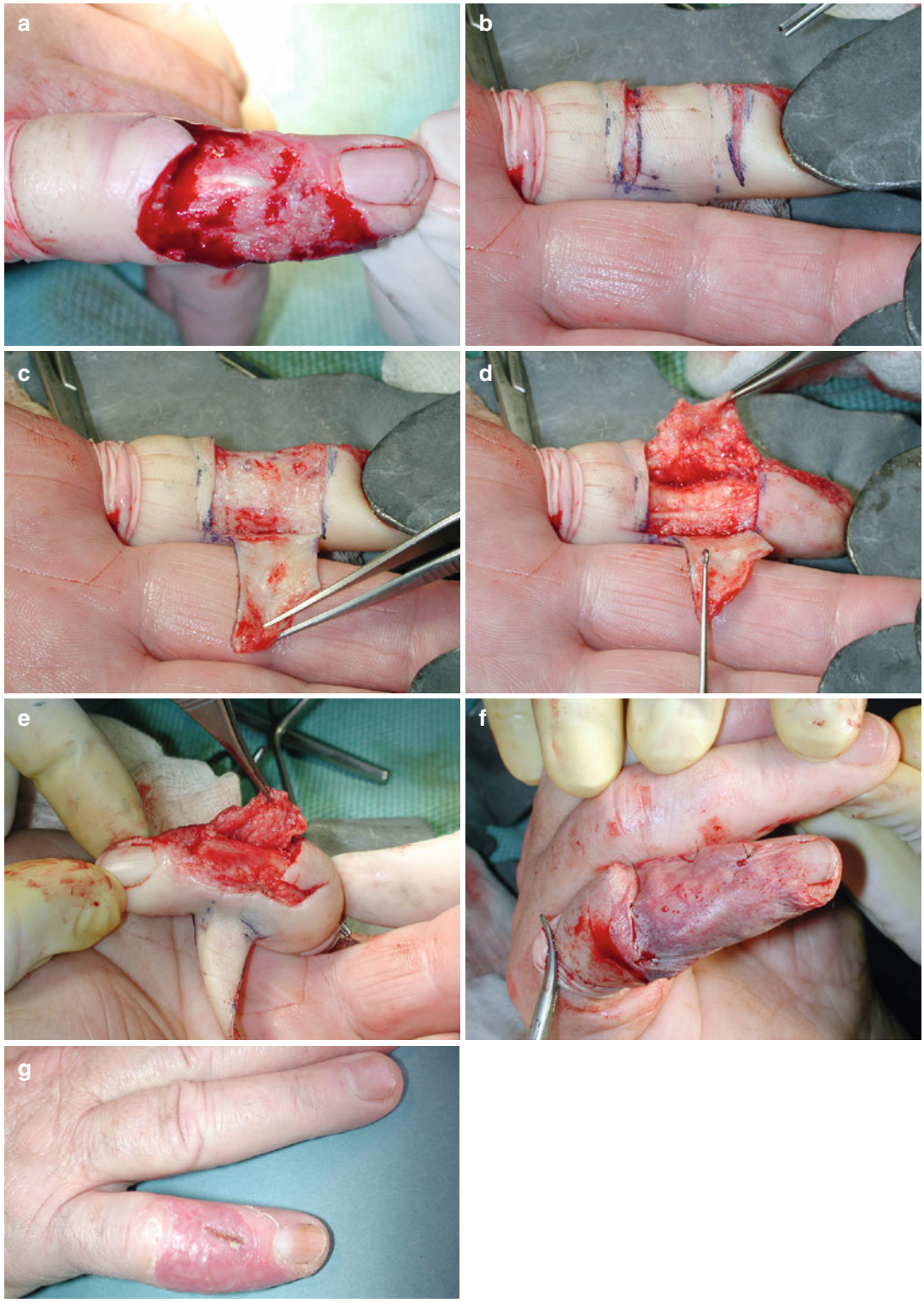


Fig. 6.7 Modified Merle flap. (**a**) Defect is dorso-ulnarly biased therefore the flap is raised on the closest (ulnar) neurovascular bundle. (**b**) Skin flap elevation. (**c**) Exposure of adipofascial plane. (**d**) Raising of adipofascial flap. (**e**) Inset. (**f**) Skin grafting of flap. (**g**) Final result

Dorsal Metacarpal Artery Perforator Flaps (Quaba Flap)

Indications

Dorsal proximal phalanx defects, webspace defects.

Technique and Refinements

First described as the "distally based hand flap" by Quaba in 1990, this perforator flap originates from the perforating branch going from the palmar to the dorsal metacarpal artery, approximately 0.5–1 cm proximal to MCPJ (Fig. 6.8) [42]. The original flap will reach up to the PIPJ. Murayama has described a similar flap, but incorporating the dorsal metacarpal artery proper into the flap [43]. There are no major advantages to this and it entails a more complex dissection. Extended variations of the dorsal metacarpal

Fig. 6.8 Quaba flap. (**a**, **b**) Defect exposing tendon of middle finger. (**c**) Doppler signal of perforating vessel. (**d**) Inset of flap and graft of secondary defect. It is normally possible to close the secondary defect primarily but in this case skin laxity was limited by previous amputations. (**e**) Example of Quaba flap with primary donor site closure

artery flap have been described which will reach up to the fingertip, but these result in an extensive scar not respectful of the dorsum of hand, and alternative options should be considered.

Limitations
Unreliable in hand infection

Advantages
Local source of well vascularised tissue, relatively straightforward

Outcomes
In a review of 69 cases, there were 7 partial losses and 3 total losses. All total losses occurred in hand infections, therefore it is not recommended in this scenario. No difference in outcomes between flaps raised on the radial or ulnar side of the hand, as long as the perforating vessel was present on Doppler [44].

Volar Finger Defects

Options
I. Cross finger (see earlier)
II. Free Venous flaps (see later)
III. Free PIA (see later)
IV. Free 1st webspace (see later)
V. Pedicled groin flap
VI. Reverse Radial Forearm

In volar finger injuries numerous flaps can be used. In small non-graftable defects a cross finger flap is a reliable option, but in larger defects we consider small free flaps to be an excellent method of resurfacing the finger, without damaging a normal donor finger. We describe the use of small free flaps later.

In single digit non-replantable degloving injuries, with the exception of the thumb, primary amputation should be strongly considered. Multiply injured fingers may require the use of a pedicle groin flap, reverse radial forearm or free flap. In volar injuries requiring revascularisation, a venous flow through flap can be used for both flap cover and arterial conduit. We have previously described the use of a syndactylised reverse radial forearm flap for multiple digit injury, using a caliber-matched perforator from the radial artery for revascularisation of a digit [45]. This technique allows simultaneous large surface area flap cover and revascularisation.

Outcomes of Fingertip Reconstruction

There is a paucity of high level evidence for outcomes in fingertip reconstruction, with the majority of methods supported by case series or expert opinion only. There are no level I or II studies on fingertip reconstruction.

Level III Evidence – Retrospective Comparative Reviews

There are a number of retrospective and prospective comparative reviews, but the majority of these are limited in their comparison of techniques.

Soderberg et al. looked at various methods of reconstruction (graft, primary closure and flaps) versus conservative management in fingertip amputations with bone exposure, in a retrospective comparative study [46]. These were divided into two groups, conservative versus surgical, with no sub-analysis of each type of closure method performed. There were 36 conservatively managed fingertips and 34 surgically treated, and follow up varied from 6 months to 4 years. The conservative treatment group fared better in terms of 2PD, pain and precision grasp. Number of lost working days was equivalent in both groups. This study suggests that conservative management of fingertip injuries results in better outcomes than surgical intervention. However, as there is no analysis of each individual surgical method, the poor results in the surgical group may have been biased by one particularly poor method, such as split skin grafting.

Ma et al. performed one of the largest prospective comparative studies, looking at 140 cases of fingertip injuries, with 7 different techniques [2]. These included SSG, FTSG, revision amputation, VY advancement, Kutler flaps, cross finger flaps and dressings alone. Final assessment was performed on all cases at 6 months and a standardized examination performed.

Outcomes were analyzed as follows (Table 6.1):

1. Healing problems – greatest in cross finger flaps with 27 % incidence of infection or graft loss, followed closely by Kutler flaps at 23 %. The other methods were comparable with healing problems in 11–17 %.
2. Cosmesis – scored from 1 (poor) to 4 (excellent) by both patient and the surgeon. In general the scores for all methods were similar, with the best scores for the VY plasty.
3. Scar tenderness. The scar sensitivity was worst for SSG (59 %) and dressings alone (54 %), correlating with the lack of thick padding over the distal phalanx.
4. Static 2 PD sufficient for tactile gnosis (<6 mm) was recovered with VY plasty, Kutler flaps, revision amputation and dressings. 2PD was worst in the skin grafted and cross finger flaps groups at 6.2–7.2 which would be insufficient for tactile gnosis.

Table 6.1 Level III evidence prospective comparative review (outcomes at 6 months) Ma et al. [2]

	Healing problems (graft loss, wound infection)/%	Appearance (1 poor – 4 excellent)	2PD/mm	Scar tenderness %	Stiffness (Loss of TAM in degrees)	Power grip/kg	Pinch grip/kg	Return to work/days
SSG	11	2.7	6.2	59	10	20.6	2.7	46
FTSG	14	2.6	6.8	26	14	23	3.2	51
VY Plasty	17	2.9	4.3	31	14	21.2	3	42
Kutler	23	2.3	3.9	31	18	22.2	3.5	52
Revision amputation	11	2.5	4.1	46	13	21.4	2.4	52
Cross finger flap	27	2.7	7.2	23	20	17.6	1.7	87
Dressings	All delayed healing	2.5	3.8	54	6	21.6	2.4	41

Table 6.2 Outcomes of soft tissue reconstruction of the digits

Technique	2PD/mm	Comments	Papers	Highest level of evidence
Dressings alone	3.8	Prolonged healing time	Ma (1982) [2]	III
Skin grafts	6.2 SSG 6.8 FTSG	Poor quality fingertip, scar sensitivity	Ma (1982) [2]	III
VY Flaps	4.3 6 mm	Short advancement	Ma (1982) [2] Lorea (2006) [15]	III IV
Hatchet flap	6.3 mm	Avoids scar on functiona surface	Tuncali (2006) [17]	IV
Kutler/Segmuller	3.9 mm		Ma (1982) [2]	III
Venkatswami/Homodigital advancement island flaps	3–6 mm	Cold intolerance 80 %, extension lag if night splint not used	Lanzetta (1995) [21]	IV
Reverse Homodigital	5.7	Tedious dissection	Yazar (2010) [28]	IV
Cross finger flaps	7.2 7.6	Restoration of tactile gnosis, donor site morbidity	Ma (1982) [2] Nishikawa (1992) [33]	IV
Innervated cross finger	3.6 mm		Lassner (2002) [31]	IV
Free toe pulp for digits other than thumb	13.1 mm	Microsurgical expertise required	Del Pinal (2004) [65] Lin (2007)	IV
Toenail	N/A		Endo (2002) [38]	IV
Turnover adipofascial	8 mm	Not recommended for finger pulp	Laoulakos (2003) [35]	IV

5. Stiffness – Cross finger flaps resulted in the greatest loss of total active range of movement (TAM) of 20°. Kutler flaps resulted in loss of 18° mainly at the DIPJ. Dressings resulted in the least finger stiffness.
6. Power – overall power and pinch grip was comparable in all groups except cross finger flaps. Loss of power was attributed to the prolonged period (2–3 weeks) of immobilization.
7. Return to work and sick leave – although management with dressings took longest for complete wound healing (28 days) they paradoxically returned to work the earliest at 41 days. Cross finger flaps took twice as long to return to work than other methods at 87 days.

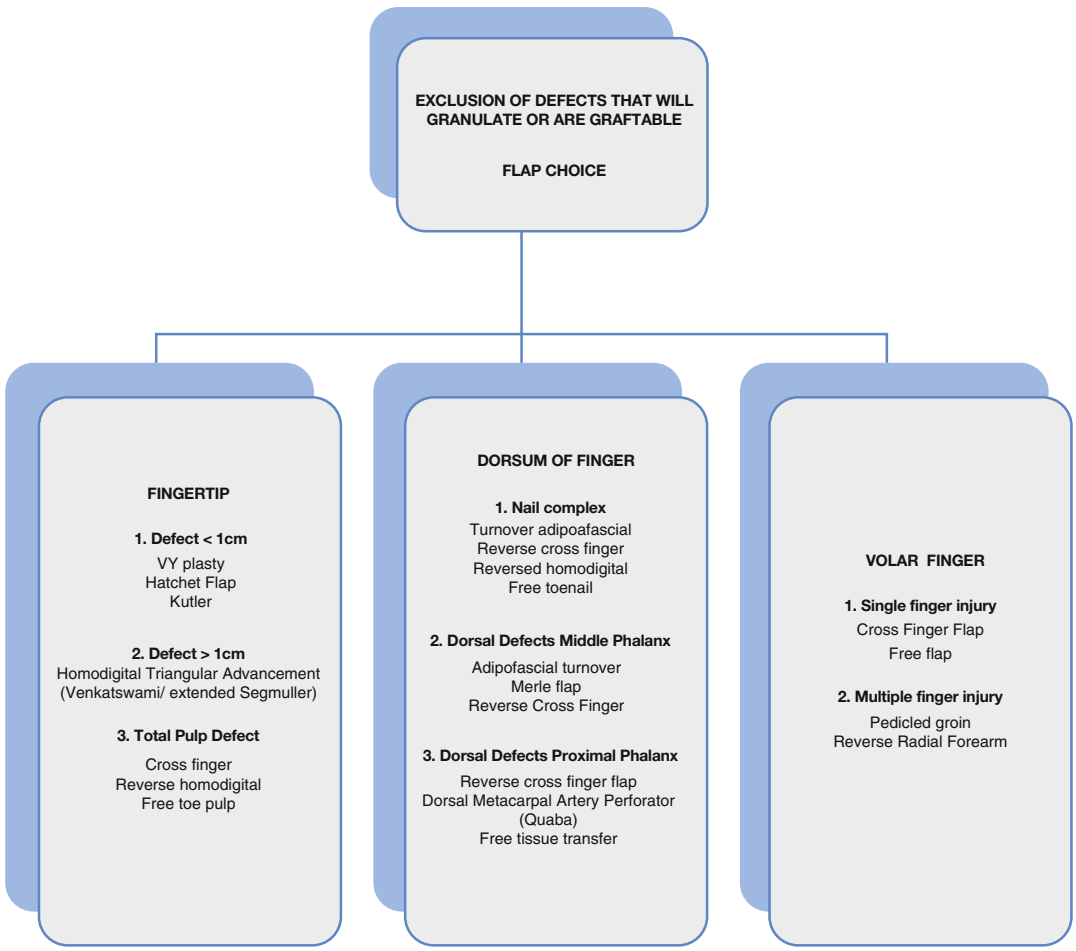
In this series the cross finger flaps resulted in the worst overall outcomes, whilst VY plasty appeared to give the best overall outcomes. Although dressings only also gave good results, the quality of the resultant tip was poor as indicated by the high incidence of scar sensitivity. Skin grafting produced tender fingertips with poor sensation.

Level IV Evidence – Non-comparative Case Series

There are numerous non-comparative retrospective reviews. These are generally unhelpful in isolation, as they do not allow valid comparison of techniques (Table 6.2).

Algorithm for Management

(Flow Chart 6.1)



Flow Chart 6.1 Algorithm for soft tissue defects of the digits

Part 3. The Thumb

Classification

Lister has described four types of thumb deficit requiring reconstruction [47]:

1. Length acceptable, cover is poor (i.e. distal defects)
2. Subtotal, length required
3. Total thumb amputation with intact CMCJ, thenar muscles
4. Total thumb amputation lacking CMCJ and thenar muscles

In this chapter we discuss only options for type 1 deficits. Maintenance of length in such injuries is crucial, as 40 % of hand function is related the thumb, and 50 % of thumb function is lost at amputation at IPJ level [6].

Local Flaps

Homodigital Flaps

Options

I. Palmar Advancement Flaps (Moberg Flap)
II. Switch flap
III. VY advancement flaps (See earlier)
IV. Adipofascial turnover flaps (see earlier)

Palmar Advancement Flaps (Moberg flap)

Indications
Volar defects <2 cm

Technique and Refinements
The palmar advancement flap was originally described by Moberg in 1964, without detachment of the flap base [47]. It has been subject to numerous modifications since, the most significant being the complete islanding of the flap to allow greater advancement and reduce risk of flexion contracture. Other refinements relate predominantly to methods of resurfacing the secondary defect [48, 49]. We prefer to use the VY modification popularized by Elliot (Fig. 6.9).

Limitations
Concerns regarding flexion contracture are not borne out by the literature, however judicious post-operative therapy is required

Advantages
No need for cortical re-orientation, excellent sensory recovery, reliable

Outcomes
Foucher reviewed 12 cases noting a 2PD of 5 mm and grip strength/ROM equivalent to contraleral side and no flexion contractures [50]. Baumiester reviewed 25 cases finding a surgical revision rate of 22 %, predominantly amongst flaps performed by trainees and in larger defects >2 cm. No statistically significant loss of range of movement at the IPJ nor flexion contractures were noted. Eighty-three percent defects were closed without the need for additional bone shortening. Normal sensation noted in 74 % and no loss of grip strength unless thumb length was lost [51].

Switch Flap

Indications
Longitudinal defects of the ulnar thumb pulp

Technique and Refinements
Originally described as an "exchange" flap for use in resurfacing the radial hemi-pulp of the index finger [52], it has been used in the thumb to resurface the functional ulnar surface by Elliot in 2003. The intact radial hemi-pulp is transferred to the ulnar side, with skin grafting to the secondary defect (Fig. 6.10).

Limitations
Violates the radial thumb pulp, therefore caution in certain professions (typists and musicians)

Advantages
Simple, innervated glabrous skin

Outcomes
Elliot reviewed 3 cases. Cortical re-orientation occurred in only 1, but despite this the

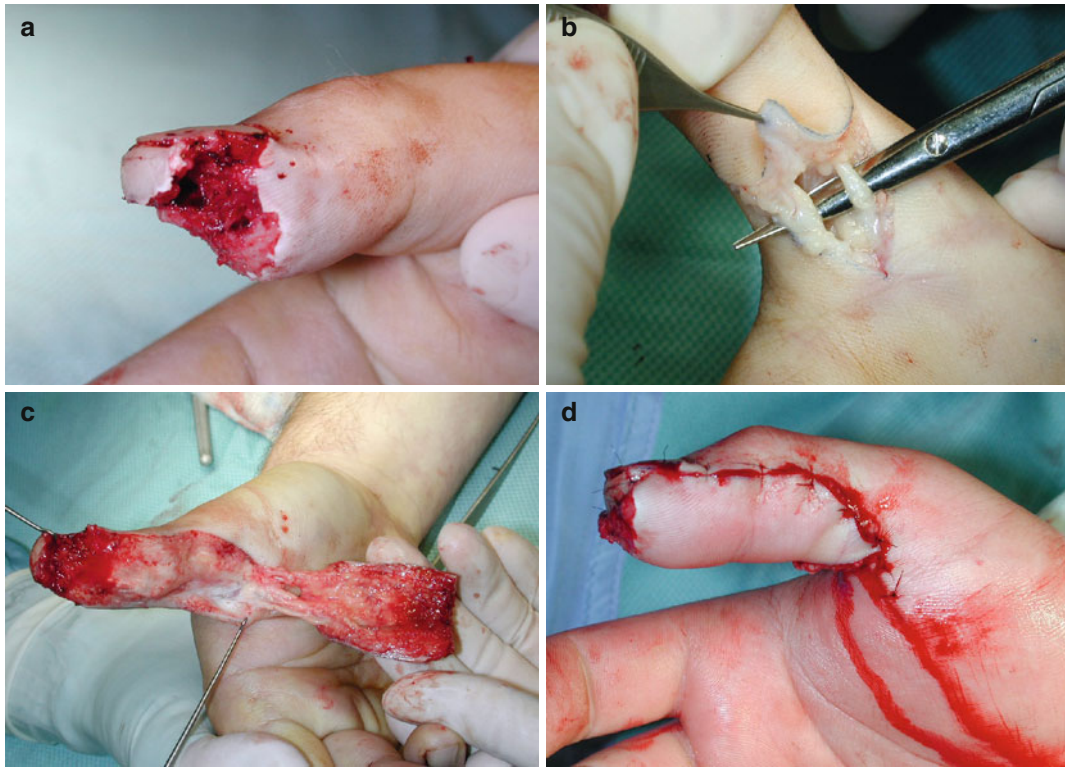


Fig. 6.9 VY modification of Moberg advancement flap. (**a**) Thumb tip defect. (**b**) Neurovascular bundles raised and preserved. (**c**) Flap fully dissected from thumb. (**d**) Inset with VY advancement at base

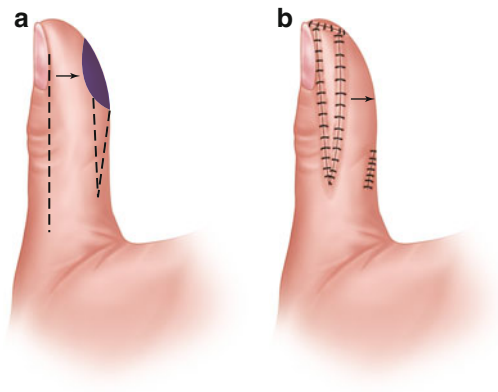


Fig. 6.10 Switch flap. (**a**) Triangulation of ulnar thumb defect. (**b**) Switching the radial pulp to the ulnar side

reconstructed switch flap was used as the "pinch" contact point rather than the more proximal thumb [53].

Heterodigital Flaps

Options

I. Heterodigital Neurovascular Island Flaps (Littler/Buchler Flaps)
II. First Dorsal Metacarpal Artery Flaps (Foucher Flap)
III. Cross finger flaps (See earlier)

Heterodigital Neurovascular Island Flaps (Littler/Buchler Flaps)

Indications

Thumb pulp sensory restoration, as part of osteoplastic thumb reconstruction. Can be used for other digits (not recommended)

Technique and Refinements

One of the landmarks in hand surgery was the development of the neurovascular island flap by

Littler in 1946 [54]. Heterodigital island flaps have generally fallen out of favour, partly due to the deleterious effect on the donor finger but also because long term cortical re-orientation does not occur in the majority of patients, resulting in the dual location phenomenon. Although Foucher described the "dibranchement-rembranchement" technique for local co-aptation, this results in loss of 2PD and therefore sensory discrimination [55]. Furthermore, as a general principle, the use of a normal uninjured finger as a donor site is best avoided.

Buchler described a variation on the Littler flap by dissecting the dorsal branch of the digital nerve from the digital nerve proper, and utilizing a skin island from the dorsum of the middle phalanx, hence terming it the "dorsal middle phalangeal flap". This preserves the digital nerve proper to the fingertip pulp, and also minimizes donor site morbidity [56]. It has also been employed as a retrograde and antegrade pedicled flap, and rarely as a free flap. The versatility of this flap allows it to reach the tip of length preserved thumbs, the fingertips of other digits, and the wrist crease.

Limitations

Cortical re-orientation poor, extensive scarring in hand, violates a normal finger

Advantages

Source of innervated glabrous skin when no local option is available, such as in osteoplastic thumb reconstruction.

Outcomes

Despite near normal tactile gnosis (19 out of 20 cases) cortical re-orientation occurs in only 25 % cases at 10 years [57]. Oka described using local co-aptation ("dibranchement-rembranchement"), which increased the cortical re-orientation rates from 61 to 100 %. In their study they found no significant deterioration in 2PD when local co-aptation was performed [58]. A series of 43 "dorsal middle phalangeal flaps" found a 100 % survival and a static 2PD of 10 mm. Although the donor finger sensibility was preserved completely in 81 % cases, hyperaesthesia was also noted in 12 % [59].

First Dorsal Metacarpal Artery Flap (FDMCA/Foucher Flap)

Indications

Pulp or dorsal defects up to the thumb tip in length preserved thumbs. Large defects >2 cm. The flap will reach the tip of a length preserved thumb

Technique and Refinements

Described initially by Hilgenfeldt in 1950 and Holevitch in 1963, it was popularized by Foucher in 1979 as the "kite" flap, with a modification from a peninsular to an islanded flap [60–62]. The vascular supply of this flap comes from the ulnar branch of the first dorsal metacarpal artery. The radial branch supplies the thumb and an intermediate branch supplies the 1st webspace. In 90 % cases the flap pedicle lies parallel to 2nd MC shaft but in 10 % it lies in the midline of the web. As the relative depth of the pedicle varies, with 57 % suprafascial and 43 % subfascial, the epimyseum of the first dorsal interosseus and the periosteum of the radial half of the second metacarpal shaft should therefore be taken with the pedicle (Fig. 6.11) [63]. Particular care should be taken in the dissection around the extensor hood.

As the 2PD of the dorsum of the index is 12–15 mm, it is at the upper limit of that which is useful for sensory discrimination, and significantly above that required for normal tactile gnosis [62]. In series using superficial branches of the radial nerve for innervation, 2PD averages 10.57 mm [63]. Furthermore, in the original series by Foucher, due to problems with cortical re-orientation, this flap was not recommended for the sensory surfaces of the thumb. Complete re-orientation may be seen in as few as 14 % [63].

Minor refinements include the inclusion of a small dart of skin attached to the skin paddle in order to spatulate the wound closure, and avoiding the raising of flaps distal to the PIPJ of the index finger due to issues of reliability and stiffness of the donor finger.

Limitations

Need for cortical re-orientation limits the usefulness of this flap for sensory restoration of the thumb pulp. 2PD insufficient for tactile gnosis.

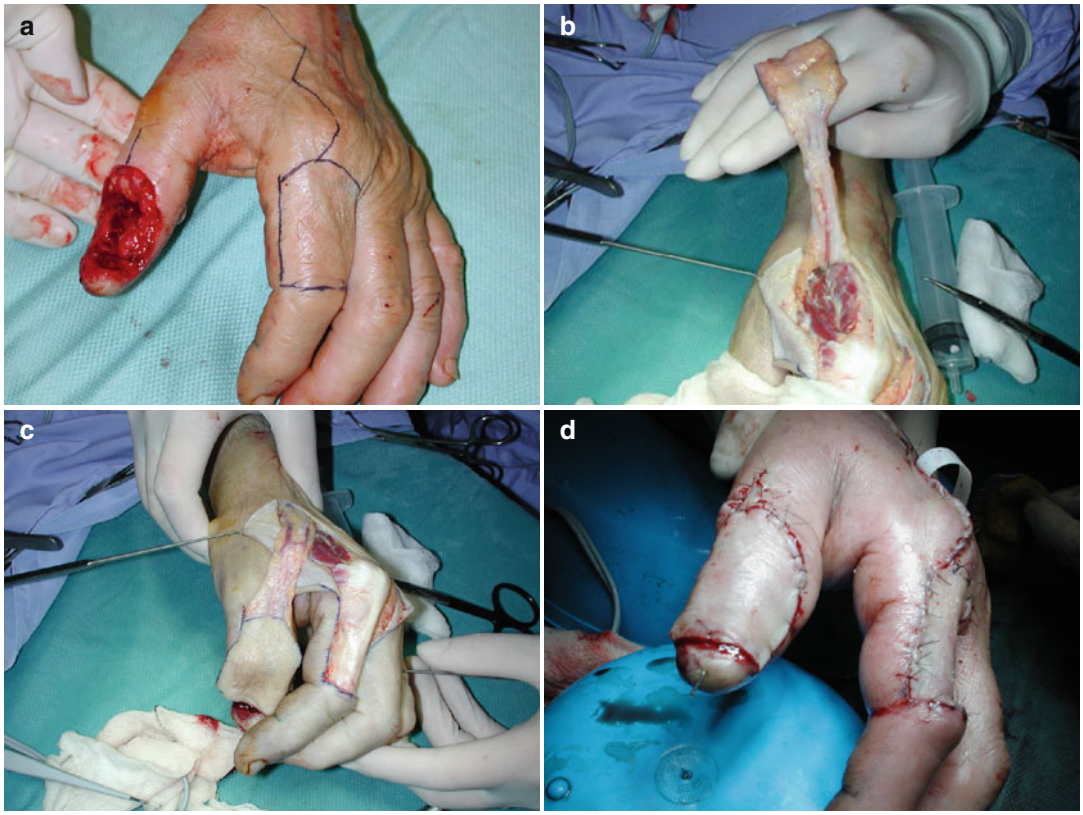


Fig. 6.11 Foucher flap. (**a**) Defect and flap planned over P1 only. (**b**) Flap demonstrates the vascular pedicle. (**c**) Flap reaches easily to tip of thumb. Note the venous plexus preserved dorsally. (**d**) Skin grafted donor site

Advantages

Useful for dorsal thumb defects or defects of the thumb too large for Moberg flap (>2 cm)

Outcomes

In a review of 25 cases of an innervated FDMCA flap, the outcomes at 3 years were static 2PD 10.9 mm, and cortical re-orientation in only 50 %, with no difference between old and young patients. The donor finger was marginally stiffer than the contralateral index with a loss of total active range of motion of 14° [64].

Distant Pedicled Flaps

Distant pedicled flaps are useful for larger defects of the thumb and degloving injuries. There are a multitude of options available including the chest, abdomen, groin and contralateral arm.

Free Flaps

Toe Pulp and Variations (Great Toe Pulp, Tibial Neurocutaneous Flap, Toe Wraparound)

Indications

Total Thumb Pulp Loss with the aim to restore sensation and provide shear resistant pinch grip. Some authors have extended the indications for use in digits other than the thumb [65]

Technique and Refinements

First described by Buncke in 1979 and Foucher in 1980, the great toe pulp microvascular free flap has gained popularity in Microsurgical centres as a method of resurfacing the thumb pulp [66, 67]. The technique of dissection is essentially the same

as that for toe transfer and is not elaborated further here (Fig. 6.12). There are however a number of refinements that can be utilized. Firstly, the short pedicle concept, as described for toenail transfer, allows a more aesthetically respectful donor and recipient site dissection [38]. Secondly, if donor vessels are taken at the Y-junction in the first webspace, this obviates the need for dissection of a plantar or dorsal system. This also entails a more rapid and less damaging dissection [65]. Thirdly, extensive stripping of the arterial adventitia can help prevent vasospasm, which is not uncommon in transfers from the foot [68]. Del Pinal has also described a "Tibial neurocutaneous flap" which takes the medial aspect of the second toe with the digital nerve, rather than from the lateral aspect of the great toe which is usually taken with the digital nerve and deep peroneal nerve. This minimizes first webspace donor site problems. This is performed under axillary and epidural blocks, with an average operating time of 4 h [65].

The toe wraparound flap described by Morrison in 1980, is a variation of the classic great toe flap, utilizing an intercalary bone graft and wrapping the soft tissue transfer around this construct. It is mentioned only briefly here as its

Fig. 6.12 Toe pulp transfer. (**a**) Failed composite graft – total pulp. (**b**) Great toe pulp lateral aspect taken. (**c**, **d**) Dorsal system dissection. (**e**) Inset to digital artery and dorsal veins, rather than snuffbox dissection. (**f**) Donor site

Fig. 6.13 Toe wraparound. (**a**, **b**) Thumb defect after crush injury in machinery, and failed revascularisation. (**c**) Toe wraparound flap. (**d**) Flap in-situ. (**e**) Long term aesthetic result

use is predominantly for loss of thumb length rather than soft tissue cover per se, although in rare instances it may be used in degloving injuries (Fig. 6.13) [69].

Limitations

Classically these have been indicated only for thumb pulp reconstruction, but some authors advocate its use in digits other than the thumb [65, 70]. Donor site problems.

Advantages

Aesthetics, glabrous skin

Outcomes

Lin et al. reviewed 15 toe pulp transfers, with a static 2PD of 13.1 mm, but 3 flaps were able to discriminate 1 point only. Semmes-Weinstein monofilament testing revealed diminished light touch in 40 % and diminished protective sensation in 53 % and loss of protective sensation in 7 % [71].

Outcomes in Distal Thumb Reconstruction

There are no Level I (meta-analysis of RCT) or Level II (Randomised Controlled Trial) studies to support the ideal reconstructive method for soft tissue loss of the thumb.

Level III Evidence – Retrospective Comparative Reviews

Woo et al. published a retrospective comparative review of 5 microvascular techniques used in partial thumb defects [72]. 43 thumb reconstructions were performed with a 100 % survival rate. For thumb pulp defects, 8 cases of lateral great toe pulp transfer were reviewed at 10 month follow-up, with a 2PD of 6 mm, key pinch 95 % of the contralateral side and IPJ ROM of 65°. For dorsal thumb defects, 4 cases of dorsalis pedis flap were assessed, with a 2PD of 15 mm, key pinch 75 % of contralateral side, and IPJ ROM 32°. There were 18 composite partial defects of the thumb, for which partial great toe transfers were done, with a 2PD 9 mm, key pinch 80 % of contralateral side, and IPJ ROM 48°. Additionally there were 10 first webspace and 3 nail complex transfers, but outcomes such as 2PD were not relevant to these cases. Overall, this study indicated that microvascular transfers to restore thumb defects are reliable, with excellent aesthetics and relatively good 2PD in great toe pulp transfers. A 2PD of 6 mm is in fact greater than that which is possible in the toe in its native position. The exact mechanism of this is unknown but may be related to the constant post-operative stimuli. However, not all studies have indicated such excellent sensory results following toe pulp transfer [65, 71].

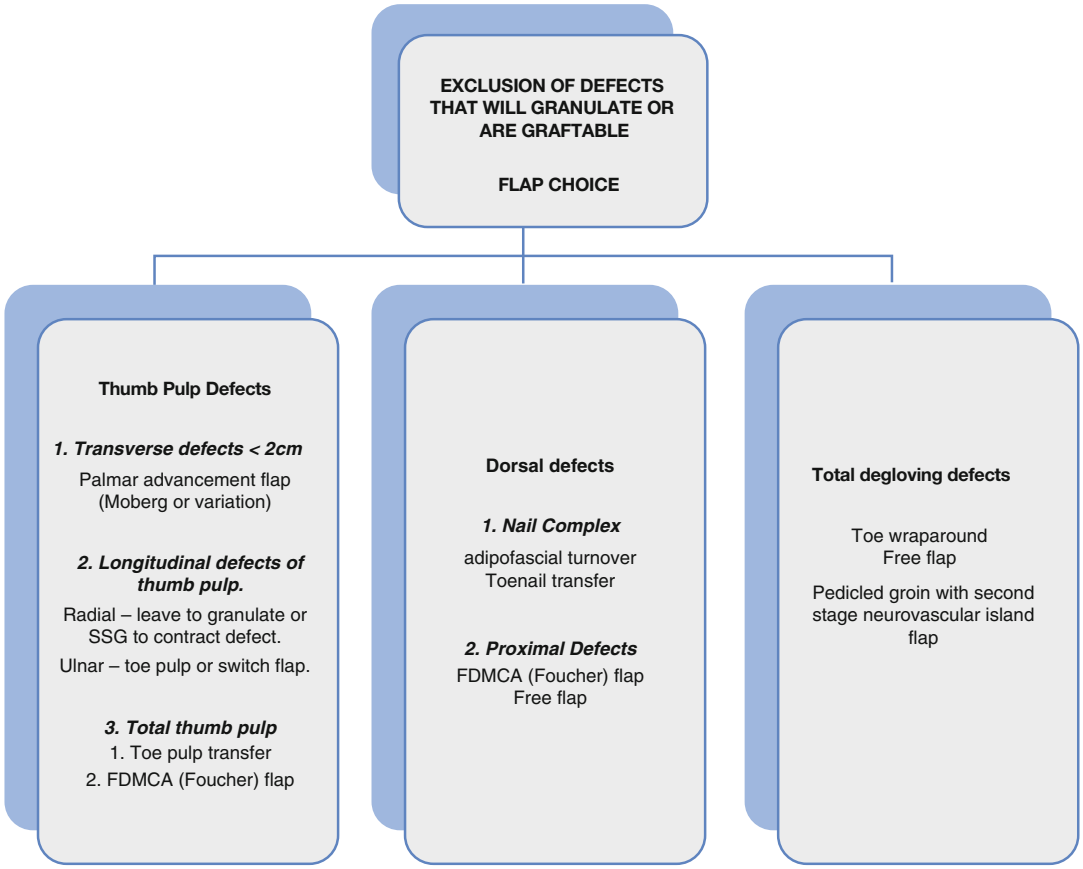
Level IV Evidence – Non-comparative Case Series

The literature strongly favours the Moberg flap as the pedicled flap of choice in thumb tip defects, due to its excellent 2PD and lack of need for cortical re-orientation. However, no Level III outcome data exists to support this. Retrospective cohort reviews by both Foucher and Baumiester confirm excellent restoration of sensory restoration with a 2PD of 5 mm and grip strength/ROM equivalent to the contraleral side. Flexion contractures are not seen when appropriate therapy is instituted. The main advantage over heterotopic flaps is that cortical re-orientation is un-necessary, rendering the thumb functionally useful immediately, thereby facilitating post-operative rehabilitation. Both reviews conclude that the Moberg flap is the ideal flap for defects <2 cm of the thumb pulp [50, 51].

Although technically elegant, the First Dorsal Metacarpal Artery Flap has two major problems for thumb pulp resurfacing. Firstly, the sensory discrimination is poor, and secondly cortical re-orientation occurs in only 50 % [73]. A similar problem exists for heterodigital neurovascular island flaps such as the Littler flap, with only 25 % achieving cortical re-orientation at 10 years [57]. Additionally, one violates a healthy donor finger, a problem that can be partially circumvented by the use of the Dorsal Middle Phalangeal flap. Although problems of cortical re-orientation in heterotopic flaps may be ameliorated by the technique of "dibranchement-rembranchement", there are reservations concerning loss of sensory discrimination with this technique (Table 6.3, Flow Chart 6.2) [55, 58]. Furthermore, this inevitably delays full post-operative rehabilitation and functional use of the hand.

Table 6.3 Outcomes of soft tissue reconstruction of thumb

	2PD	Cortical reorientation	Studies	Level of evidence
Moberg	5 mm	Unnecessary	Foucher (1999)	IV
FDMCA (Foucher)	10.8	50 %	Trankle (2003)	IV
	15		Shi (1994) [85]	IV
Neurovascular island flaps (Littler)	7	25 % at 10 years	Henderson (1980)	IV
	9.4	61–100 %	Oka (2003)	IV
Great Toe Pulp	6	N/A	Woo (1999)	III
	13.1		Lin (2007)	IV
Toe Wraparound	12 mm	N/A	Wei (1994) [86]	III



Flow Chart 6.2 Algorithm for soft-tissue only defects of thumb

Part 4: Small Free Flaps in Digital and Webspace Reconstruction

No list of flaps can be exhaustive, and we include only some of the commoner flaps in use. However, an emphasis has recently been placed on emerging techniques in small free flap reconstruction of the digits. These are particularly useful in rare cases when local reconstructive options are not available, allowing reconstruction of digits that previously may not have been salveagable. Moreover, webspace reconstruction is particularly suited to free flap reconstruction, as the resultant quality of webspace is far superior to that which can be achieved with skin grafts alone.

Free flap reconstruction of the digits has more recently been extended by some authors to include aesthetic considerations alone [65, 70]. Cheng et al. reviewed a series of 80 cases of partial toe, toenail and toe pulp transfers for aesthetic reconstruction of digits (of which 29 were of non-thumb digits), with a 97.5 % survival rate, and 2PD varying from 4 to 10 mm [70]. In a review by Del Pinal, the conventional notions of toe pulp transfer are also challenged and microvascular transfer is performed within the acute trauma period, and is recommended particularly in manual workers [65]. Toe pulp, traditionally used in thumb reconstruction alone, is also recommended for the functional surfaces of digits such as the index and little fingers.

In a review of 18 small free flaps for the digits, a flap necrosis of 11 % and partial flap necrosis rate of 6 % was noted [74]. This series included 10 venous flow through, 1 lateral arm, 1 medial plantar, 2 free Posterior interosseus flaps, 1 toe pulp and 3 first webspace flaps. The majority of the patients regained excellent function with a

quick DASH score of 5.7. All flaps regained protective sensation only, with 2PD of 13–15 mm. Pain and cosmetic deformity were minimal, but donor site morbidity was high in first webspace flaps, with hypertrophic scarring around the donor site in all cases. Endo has described the use of artificial dermis which may obviate some of these problems [38]. This review concludes that the venous flow through flap is the preferred free flap choice for the digits, due to its ease of dissection, versatility of pedicle design and limited donor site morbidity. Although first webspace flaps result in excellent digit reconstruction characteristics, their use is generally avoided due to unacceptably high donor site complications.

Perceived drawbacks of free flap reconstruction of the digits include the lack of sufficient sensation in most flaps for tactile gnosis (except toe pulp), prolonged operating time and the need for relative technical expertise. However, in Specialist Centres the latter two issues are not of concern.

Options

I. Venous Flow Through Flap
II. Posterior Interosseus Flap
III. Medial Plantar
IV. First Webspace
V. Toe Pulp (see earlier)
VI. Toe Nail (see earlier)

Venous Flow Through Flap

Indications

Defects proximal to the fingertip, large finger defects, webspace reconstruction, degloving defects requiring revascularisation and skin cover

Technique and Refinements

Thatte and Thatte have described three variants: Type I – venous unipedicled, Type II – venous-venous and Type III – arterio-venous [75]. Chen has additionally described artery-artery flow through flaps [76]. As the pedicle requires only a single vein or plexus of veins, the donor sites are numerous. For reconstruction of the digits, the volar wrist skin has a number of veins in an "H" configuration, which offer an ideal thin and pliable flap. This site also offers the opportunity to take Palmaris longus or small cutaneous nerve branches such as the palmar cutaneous branch of the median nerve or lateral antebrachial for innervation. The flap is designed after marking the veins and direction of flow, prior to tourniquet inflation (Fig. 6.14). Post-operative flap congestion and oedema may mimic venous compromise. However, normal Doppler signals from the efferent veins and bright red pin-prick bleeding are indicative of healthy perfusion.

Limitations

Perceived high failure rates not supported by large series

Advantages

Thin, pliable flap ideal for small hand defects, does not sacrifice a major artery. Can be used for composite defects requiring tendon or nerve. Good caliber match for small digital arteries and veins.

Outcomes

Large series of type III arteriovenous venous flaps have failure rates of 2–3.6 % [76, 77]. We recommend using arteriovenous or artery-artery flow through flaps in preference to Type II veno-venous flaps, as these have a more questionable reliability [76].

Free Posterior Interosseus Flap

Indications

Defects requiring very thin tissue resurfacing, particularly dorsal hand defects, first webspace and digits.

Technique and Refinements

First described as a pedicled flap by Zancolli and Angrigiani in 1988, this flap is based on the posterior interosseus artery [78]. This in turn is derived from the common interosseus artery, a branch of the ulnar artery, which divides into a posterior and anterior branch. The posterior interosseus artery lies deep to supinator, and its surface landmarks

Fig. 6.14 venous flow through flap. (**a**) Dorsal composite index finger defect. (**b**) Relatively innocuous donor site, note the direction of flow is marked prior to elevation. (**c**, **d**) Type III Arteriovenous flow through flap to the digital vessels

are the junction of the proximal and middle thirds of a line between the lateral epicondyle and the distal radio-ulnar joint. The vessel lies in the septum between extensor compartments 5 and 6. Identification of the correct extensor compartments is easiest to perform at the wrist initially, followed by an approach to the vessel from radial to ulnar (Fig. 6.15). Although the artery carries its own venae comitantes, some authors recommend that a cutaneous vein should be harvested with the flap if it is to be used as a free flap [79].

Limitations

Relatively small caliber pedicle, but good match for digital vessels

Advantages

Thin, can be raised as an fascial flap only, long pedicle

Outcomes

Chen reported 36 cases of free PIA with a success rate of 97 % [79].

Free Medial Plantar Flap

Indications

Small pulp defects or other areas requiring glabrous skin such as the hypothenar aspect of the palm.

Technique and Refinements

The medial plantar flap was described as a free flap for resurfacing the palm by Hidalgo in 1986, and as a method for finger pulp reconstruction by Inoue in 1988 [80, 81]. A number of case series report the successful use of small free medial plantar flaps, with or without reinnervation for finger pulp reconstruction [82, 83].

Fig. 6.15 Free fascial PIA. (**a**) Free PIA to cover traumatic longitudinal finger after DIPJ arthrodesis. (**b**) Split skin graft cover. (**c**, **d**) Final post-operative views

The medial plantar flap has a relatively consistent pedicle between the abductor hallucis brevis and flexor digitorum brevis, although a cutaneous branch of the saphenous vein should additionally be taken for anastamosis when used as a free flap. Reinnervation can be performed to either a cutaneous branch of medial plantar nerve or the terminal cutaneous branch of the saphenous nerve. The medial plantar nerve originates 1–3 cm distal to the medial malleolus, giving off three cutaneous branches to the medial plantar skin. One or more of these branches can be taken with the flap, with intraneural dissection allowing greater length.

Limitations

Relatively easy to raise when taken as a short pedicle transfer. Donor site problems

Advantages

Allows a greater surface area of glabrous skin for resurfacing of larger defects than the toe pulp flap.

Outcomes

Huang described 10 cases for finger reconstruction with a 2PD of 8.8 mm without reinnervation, 20 % donor site problems, 90 % total flap survival, and 10 % partial flap loss [83]. Lee reviewed 6 cases of pulp reconstruction with small medial plantar flaps with reinnervation, with follow up at 2 years indicating a 2PD of 5.2 mm [82].

First Webspace Free Flap/Dorsalis Pedis Free Flap

Indications

Webspace reconstruction, larger finger defects

Technique and Refinements

Described as early as 1977 [84], the anatomy and dissection are essentially the same as that for raising the toe pulp flap. An "extended" flap can be designed, incorporating the first

Fig. 6.16 First Webspace flap. (**a**) Complete volar loss of middle finger. (**b**) Extended 1st webspace flap (or Type III flap according to the classification of Woo 1999). (**c**) Dorsal system. (**d**) Flap in-situ

webspace, the lateral aspect of great toe and the medial aspect of second toe. A flap of up to 7.5 cm width and 14 cm length can thus be designed [68]. The vascular and nerve supply in this area allow great versatility in flap design, with the deep peroneal nerve or digital nerves to both toes, and the dorsal or plantar metatarsal artery and digital branches to both toes, available for inclusion. The first webspace flap has been classified into 4 types based on this versatility [68]:

Type 1: the webspace proper

Type 2: a two island skin flap taken separately from the great and second toes, based on separate digital vessels and nerves

Type 3: fill-up web flap – basically a long dorsalis pedis skin flap (Fig. 6.16)

Type 4: adjuvant web flap – when the first web or adjacent skin is taken in conjunction with a vascularised joint transfer

Limitations

Donor site problems

Advantages

Like for like construction of webspace defects of the hand

Outcomes

In a review of 31 cases a 100 % survival rate and 2PD 8.5 mm was noted [68].

References

1. Mennen U, Wiese A. Fingertip injuries management with semi-occlusive dressing. J Hand Surg Br. 1993; 18(4):416–22.
2. Ma GF, Cheng JC, Chan KT, Chan KM, Leung PC. Finger tip injuries–a prospective study on seven methods of treatment on 200 cases. Ann Acad Med Singapore. 1982;11(2):207–13.

3. Lister G. The hand. Diagnosis and indications. Edinburgh: Churchill Livingstone; 1984.
4. Moiemen NS, Elliot D. Composite graft replacement of digital tips. 2. A study in children. J Hand Surg Br. 1997;22(3):346–52.
5. Heistein JB, Cook PA. Factors affecting composite graft survival in digital tip amputations. Ann Plast Surg. 2003;50(3):299–303.
6. Swanson AB, Göran-Hagert C, de Groot Swanson G. Evaluation of impairment in the upper extremity. J Hand Surg Am. 1987;12(5 Pt 2):896–926.
7. Moberg E. Objective methods for determining the functional value of sensibility in the hand. J Bone Joint Surg. 1958;40B:454–76.
8. Moberg E. Aspects of sensation in reconstructive surgery of the upper extremity. J Bone Joint Sur. 1964;46A:817–25.
9. Dellon AL. Sensibility, re-education of sensation in the hand. Baltimore: Williams & Wilkins; 1981.
10. Lundborg G, Rosen B. The two-point discrimination test: time for a re-appraisal? J Hand Surg (Br). 2004;29:418.
11. Ishikawa K, Ogawa Y, Soeda H, Yoshida Y. A new classification of the amputated level for the distal part of the finger. J Jpn Soc Reconstr Microsurg. 1990;3:54.
12. Tranquilli-Leali E. Ricostruzione dell'apice delle falangi ungue-ali ruediante autoplastica volare peduncolata per scorrimento. Infort Traum Lavaro. 1935;1:186–93.
13. Atasoy E, Ioakimidis E, Kasdan ML, Kutz JE, Kleinert HE. Reconstruction of the amputated fingertip with a triangular volar flap. J Bone Joint Surg. 1970;52A(5):921–6.
14. Elliot D, Moiemen NS, Jigjinni VS. The neurovascular Tranquilli-Leali flap. J Hand Surg Br. 1995;20(6):815–23.
15. Lorea P, Chahidi N, Marchesi S, Ezzedine R, Marin Braun F, Dury M. Reconstruction of fingertip defects with the neurovascular tranquilli-leali flap. J Hand Surg Br. 2006;31(3):280–4.
16. Emmett AJ. The closure of defects by using adjacent tri- angular flaps with subcutaneous pedicles. Plast Reconstr Surg. 1977;59:45.
17. Tuncali D, Barutcu AY, Gokrem S, Terzioglu A, Aslan G. The hatchet flap for reconstruction of fingertip amputations. Plast Reconstr Surg. 2006;117(6): 1933–9.
18. Geissendorfer H. Beitrag zur Fingerkuppenplastik. Zentralbl Chir. 1943;70:1107.
19. Kutler W. A new method for finger tip amputation. JAMA. 1947;133:29.
20. Segmuller G. Modification of the Kutler flap: neurovascular pedicle. Handchirurgie. 1976;8(2):75–6.
21. Lanzetta M, Mastropasqua B, Chollet A, Brisebois N. Versatility of the homodigital triangular neurovascular island flap. J Hand Surg. 1995;20B:824.
22. Smith KL, Elliot D. The extended Segmüller flap. Plast Reconstr Surg. 2000;105(4):1334–46.
23. Venkatswami R, Subramanian N. Oblique triangular flap: a new method of repair for oblique amputations of the fingertip and thumb. Plast Reconstr Surg. 1980;66(2):296–300.
24. Evans DM, Martin DL. Step-advancement island flap for fingertip reconstruction. Br J Plast Surg. 1988; 41(2):105–11.
25. Lai CS, Lin SD, Yang CC. The reverse digital artery flap for fingertip reconstruction. Ann Plast Surg. 1989;22(6):495–500.
26. Kaleli T, Ersözlü S, Öztürk Ç. Double reverse-flow island flaps for two adjacent finger tissue defect [Article in Turkish]. Arch Orthop Trauma Surg. 2004;124:157–60.
27. Moschella F, Cordova A. Reverse homodigital dorsal radi- al flap of the thumb. Plast Reconstr Surg. 2006;117:920–6.
28. Yazar M, Aydın A, Kurt Yazar S, Başaran K, Güven E. Sensory recovery of the reverse homodigital island flap in fingertip reconstruction: a review of 66 cases. Acta Orthop Traumatol Turc. 2010;44(5):345–51.
29. Gurdin M, Pangman WJ. The repair of surface defects of fingers by trans-digital flaps. Plast Reconstr Surg (1946). 1950;5(4):368–71.
30. Heng D, Zhang C, Yao Y, Liu L, Chen YI. Experimental study on early division of cross-finger pedicle flap and its clinical application. Chin J Traumatol. 2000;3(3):159–62.
31. Lassner F, Becker M, Berger A, Pallua N. Sensory reconstruction of the fingertip using the bilaterally innervated sensory cross-finger flap. Plast Reconstr Surg. 2002;109(3):988–93.
32. Atasoy E. Reversed cross-finger subcutaneous flap. J Hand Surg Am. 1982;7(5):481–3.
33. Nishikawa H, Smith PJ. The recovery of sensation and function after cross-finger flaps for fingertip injury. J Hand Surg Br. 1992;17(1):102–7.
34. Paterson P, Titley OG, Nancarrow JD. Donor finger morbidity in cross-finger flaps. Injury. 2000;31(4): 215–8.
35. Laoulakos DH, Tsetsonis CH, Michail AA, Kaxira OS, Papatheodorakis PH. The dorsal reverse adipofascial flap for fingertip reconstruction. Plast Reconstr Surg. 2003;112(1):121–5; discussion 126–8.
36. Foucher G, Nagel D, Briand E. Microvascular great toenail transfer after conventional thumb reconstruction. Plast Reconstr Surg. 1999;103(2):570–6.
37. Koshima I, Soeda S, Takase T, Yamasaki M. Free vascularized nail grafts. J Hand Surg (Am). 1988;13:29.
38. Endo T, Nakayama Y. Microtransfers for nail and fingertip replacement. Hand Clin. 2002;18(4):615–22; discussion 623–4.
39. McCash CR. Free nail grafting. Br J Plast Surg. 1955;8(1):19–33.
40. Voche P, Merle M. The homodigital subcutaneous flap for cover of dorsal finger defects. Br J Plast Surg. 1994;47(6):435–9.
41. Jeffery SL, Pickford MA. Use of the homodigital adipofascial turnover flap for dorsal cover of

distal interphalangeal joint defects. J Hand Surg Br. 1999;24(2):241–4.
42. Quaba AA, Davison PM. The distally-based dorsal hand flap. Br J Plast Surg. 1990;43(1):28–39.
43. Maruyama Y. The reverse dorsal metacarpal flap. Br J Plast Surg. 1990;43(1):24–7.
44. Gregory H, Heitmann C, Germann G. The evolution and refinements of the distally based dorsal metacarpal artery (DMCA) flaps. J Plast Reconstr Aesthet Surg. 2007;60(7):731–9.
45. Lo S, Sebastin S, Tsai L, Pin PY. Reverse radial forearm flap peforator used in digital revascularization. Hand (N Y). 2007;2(3):155–8.
46. Söderberg T, Nyström A, Hallmans G, Hultén J. Treatment of fingertip amputations with bone exposure. A comparative study between surgical and conservative treatment methods. Scand J Plast Reconstr Surg. 1983;17(2):147–52.
47. Lister G. The choice of procedure following thumb amputation. Clin Orthop Relat Res. 1985;195:45–51.
48. O'Brien B. Neurovascular island pedicle flaps for terminal amputations and digital scars. Br J Plast Surg. 1968;21(3):258–61.
49. Elliot D, Wilson Y. V-Y advancement of the entire volar soft tissue of the thumb in distal reconstruction. J Hand Surg Br. 1993;18(3):399–402.
50. Foucher G, Delaere O, Citron N, Molderez A. Long-term outcome of neurovascular palmar advancement flaps for distal thumb injuries. Br J Plast Surg. 1999;52(1):64–8.
51. Baumeister S, Menke H, Wittemann M, Germann G. Functional outcome after the Moberg advancement flap in the thumb. J Hand Surg Am. 2002;27(1):105–14.
52. Littler JW. Principles of reconstructive surgery of the hand. In: Converse JM, editor. Reconstructiue plastic surgery, The hand and upper extremity, vol. 6. 2nd ed. Philadelphia: W. B. Saunders; 1977. p. 3139.
53. Elliot D, Southgate CM, Staiano JJ. A homodigital switch flap to restore sensation to the ulnar border of the thumb tip. J Hand Surg Br. 2003;28(5):409–13.
54. Littler JW. The neurovascular pedicle method of digital transposition for reconstruction of the thumb. Plast Reconstr Surg (1946). 1953;12(5):303–19.
55. Foucher G, Braun FM, Merle M, Michon J. La techniaue de "dibranchement-rembranchement" du lambeau. Ann Chir. 1981;35(4):301–3.
56. Büchler U, Frey HP. The dorsal middle phalangeal finger flap. Handchir Mikrochir Plast Chir. 1988;20(5):239–43.
57. Henderson HP, Reid DA. Long term follow up of neurovascular island flaps. Hand. 1980;12(2):113–22.
58. Oka Y. Sensory function of the neurovascular island flap in thumb reconstruction: comparison of original and modified procedures. J Hand Surg Am. 2000;25(4):637–43. Review.
59. Leupin P, Weil J, Büchler U. The dorsal middle phalangeal finger flap. Mid-term results of 43 cases. J Hand Surg Br. 1997;22(3):362–71.
60. Hilgenfeldt O. Operativer daumenersatz. Stuttgart: Enkeverslag; 1950.
61. Holevich J. A new method of restoring sensibility to the thumb. J Bone Joint Surg. 1963;45B:496–502.
62. Foucher G, Braun JB. A new island flap transfer from the dorsum of the index to the thumb. Plast Reconstr Surg. 1979;63(3):344–9.
63. Muyldermans T, Hierner R. First dorsal metacarpal artery flap for thumb reconstruction: a retrospective clinical study. Strategies Trauma Limb Reconstr. 2009;4(1):27–33.
64. Tränkle M, Sauerbier M, Heitmann C, Germann G. Restoration of thumb sensibility with the innervated first dorsal metacarpal artery island flap. J Hand Surg Am. 2003;28(5):758–66.
65. Del Piñal F. The indications for toe transfer after "minor" finger injuries. J Hand Surg Br. 2004;29(2):120–9.
66. Buncke HJ, Rose EH. Free toe-to-fingertip neurovascular flaps. Plast Reconstr Surg. 1979;63:607.
67. Foucher G, Merle M, Meneanen M, Michon J. Microvascular free partial toe transfer in hand reconstruction: a report of 12 cases. Plast Reconstr Surg. 1980;65:616–8.
68. Woo SH, Choi BC, Oh SJ, Seul JH. Classification of the first web space free flap of the foot and its applications in reconstruction of the hand. Plast Reconstr Surg. 1999;103(2):508–17.
69. Morrison WA, O'Brien BM, MacLeod AM. Thumb reconstruction with a free neurovascular wrap-around flap from the big toe. J Hand Surg Am. 1980;5(6):575–83.
70. Cheng G, Fang G, Hou S, Pan D, Yuan G, Wang Z, Zhang Y, Ding X, Tang H, Yang Z. Aesthetic reconstruction of thumb or finger partial defect with trimmed toe-flap transfer. Microsurgery. 2007;27(2):74–83.
71. Lin CH, Lin YT, Sassu P, Lin CH, Wei FC. Functional assessment of the reconstructed fingertips after free toe pulp transfer. Plast Reconstr Surg. 2007;120(5):1315–21.
72. Woo SH, Kim JS, Kim HH, Seul JH. Microsurgical reconstruction of partial thumb defects. J Hand Surg Br. 1999;24(2):161–9.
73. Trankle M, Germann G, Heitmann C, Sauerbier M. Defect coverage and reconstruction of thumb sensibility with the first dorsal metacarpal artery flap. Article in German. Chirurg. 2004;75(10):996–1002.
74. Turner A, Ragowannsi R, Hanna J, Teo TC, Blair JW, Pickford MA. Microvascular soft tissue reconstruction of the digits. J Plast Reconstr Aesthet Surg. 2006;59(5):441–50.
75. Thatte MR, Thatte RL. Venous flaps. Plast Reconstr Surg. 1993;91(4):747–51. Review.
76. Chen HC, Tang YB, Noordhoff MS. Four types of venous flaps for wound coverage: a clinical appraisal. J Trauma. 1991;31(9):1286–93.
77. Woo SH, Kim KC, Lee GJ, Ha SH, Kim KH, Dhawan V, Lee KS. A retrospective analysis of 154 arterialized venous flaps for hand reconstruction: an 11-year experience. Plast Reconstr Surg. 2007;119(6):1823–38.
78. Zancolli EA, Angrigiani C. Posterior interosseous island forearm flap. J Hand Surg Br. 1988;13(2):130–5.

79. Chen HC, Cheng MH, Schneeberger AG, Cheng TJ, Wei FC, Tang YB. Posterior interosseous flap and its variations for coverage of hand wounds. J Trauma. 1998;45(3):570–4.
80. Hidalgo DA, Shaw WW. Anatomic basis of plantar flap design. Plast Reconstr Surg. 1986;78(5):627–36.
81. Inoue T, Kobayashi M, Harashina T. Finger pulp reconstruction with a free sensory medial plantar flap. Br J Plast Surg. 1988;41(6):657–9.
82. Lee HB, Tark KC, Rah DK, Shin KS. Pulp reconstruction of fingers with very small sensate medial plantar free flap. Plast Reconstr Surg. 1998;101(4):999–1005.
83. Huang SH, Wu SH, Lai CH, Chang CH, Wangchen H, Lai CS, Lin SD, Chang KP. Free medial plantar artery perforator flap for finger pulp reconstruction: report of a series of 10 cases. Microsurgery. 2010;30:118–24.
84. May Jr JW, Chait LA, Cohen BE, O'Brien BM. Free neurovascular flap from the first web of the foot in hand reconstruction. J Hand Surg Am. 1977;2(5):387–93.
85. Shi SM, Lu YP. Island skin flap with neurovascular pedicle from the dorsum of the index finger for reconstruction of the thumb. Microsurgery. 1994;15(2):145–8.
86. Wei FC, Chen HC, Chuang CC, Chen SH. Microsurgical thumb reconstruction with toe transfer: selection of various techniques. Plast Reconstr Surg. 1994;93(2):345–51.