Intrinsic Flaps in Soft Tissue Reconstruction of the Hand

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A growing body of evidence has demonstrated that functional reconstruction following severe hand injuries is best achieved by obtaining primary stable soft tissue coverage in order to avoid drawbacks of delayed wound healing such as edema, excessive scarring, prolonged immobilization and joint stiffness (1,36,38,51).

The philosophy of immediate wound closure, whenever possible, lead to an interest in the development of new flaps and significant progress in reconstructive techniques for skin and soft tissue defects in the hand. Most of these flaps permit early active mobilization and/or intensive physical thereby overcoming the disadvantages of traditional distant pedicle flaps such as the cross-arm flap, the Colson-flap, the abdominal wall flap, or the pedicled groin flap.

Many experienced hand surgeons tend to follow the principle of using the injured extremity to repair ipsi-lateral defects, if this does not result in unacceptable donor scars. This limits the mutilation to the extremity involved and does not create additional donor-site morbidity. However, the choice of the reconstructive procedure is influenced by many personal factors such as sex, age, profession, concomitant diseases, aesthetic perception (personal profile of the patient). Flap choice is more dependent on the personal profile than on the characteristics of the defect. Although many differing situations are encountered, certain principles can be applied to all situations. A defect of the dorsum of the hand for example in a young woman should not be treated with a reverse radial forearm flap whereas this flap would be an optimal solution for an identical defect in a 70 year old man. Therefore, the armamentarium of the reconstructive surgeon should consist of a broad spectrum of different flaps to permit a sophisticated patient-oriented approach. Sound knowledge of the anatomy of the hand is mandatory and facilitates innovative thinking to select the best flap in the particular clinical situation.

Only few areas in hand surgery have experienced such a rapid evolution as the reconstruction of soft tissue defects in the hand with intrinsic ad extrinsic pedicled flaps (20a). New flaps or refinements of flaps are continuously reported in the literature. They are based on the clinical application of the re-discovering of anatomical studies by Spalteholz, Manchot, and Salmon on the vasculature of the hand. Although their early studies defined the intrinsic vascular anatomy of the hand, few clinical uses of this knowledge were applied to defect reconstruction including the following traditional flaps:
Table 1: Traditional flaps

- Neuro-vascular island flap \(^{(2,37,54,69)}\)
- Arterialized transposition flap \(^{(23)}\)
- Palmar sensory advancement flap \(^{(44)}\)
- Cross-finger flap \(^{(21)}\)
- Flag flap \(^{(29,39)}\)
- Cross-Arm flap \(^{(16)}\)
- Colson-flap \(^{(10)}\)
- Abdominal wall, groin flaps \(^{(42,56)}\)

Time proven traditional procedures in coverage of digital defects have fulfilled the mere purpose of covering a defect satisfactorily for many decades, but secondary donor site morbidity, prolonged immobilization, or non-satisfying quality of the provided tissue (Table 1) have lead to a joint venture of modern anatomic research and the established techniques of microsurgical flap dissection. A wide variety of muscular, cutaneous, septo-cutaneous, fascio-cutaneous, and neuro-cutaneous flaps were identified which can be utilized for tissue reconstruction within the injured hand or can be utilized as microvascular donor sites for small free flaps. The majority of these new flaps are found at the dorso-lateral aspect of the hand and digits, only some of them are raised at the palmar aspect. Venous flaps have added another dimension. Although the physiologic mechanisms of nutritive perfusion are not completely understood yet, mainly microvascular venous flaps have found entrance into the reconstructive armamentarium in selected hospitals.

Anatomy:

Numerous studies using latex injection, microscopic dissection, and ultrasound mapping have elucidated the arterial anatomy of the hand. The dorsal metacarpal and digital network, which long had been neglected, gained increasing attention, and serves as the basis for numerous versatile flaps from the dorsum of the hand and digits.

Dorsal system

The dorsal metacarpal arterial network is supplied by the radial artery or its major branch, the princeps pollicis, before diving deep to form the deep palmar arch. Four dorsal metacarpal arteries spring off the carpal arch and run distally just dorsal to the
fascia of the interosseus muscles. Another dorsal artery supplies the dorso-ulnar aspect of the thumb (Fig. 1). Ultrasound mapping studies gave us a clear picture of the course and incidence of dorsal metacarpal arteries, which are found in 100% at the radial aspect of the hand and decrease in presence and reliability towards the ulnar edge.

The dorsal metacarpal arteries communicate with the superficial palmar arch via anastomoses at the level of the metacarpal heads. They continue to the dorsum of the digits and end in a dorsal network with many branches to the subdermal plexus in the middle of the proximal phalanges. In approximately 50% of all cases they directly anastomose with the dorsal arterial network which essentially consists of a plexiform network supplied by the dorsal branches of the main palmar collateral arteries. This network is found in the subcutaneous plane above the paratenon and also serves as the basis for the cross-finger flap and its modifications (Fig. 1).

**Palmar system**

The palmar arteries are essential for the viability of the digit. They give numerous branches to the dorsal network. Constant branches with adequate caliber have been identified in the middle of the proximal phalanx and proximal to the PIP joint and serve as the vascular pedicle of dorsal digital flaps. In analogy to the arterial arches in the hand and wrist, there are communications between the collateral arteries in the distal pulp. Integrity of these distal arches facilitates the harvest of reverse pedicle flaps based on a proper digital artery. In some cases, there are sufficient anastomoses between the dorsal and the palmar network at the level of the proximal phalanx to guarantee viability of the digit, even if both palmar arteries have been severed. Inclusion of dorsal or palmar sensory nerves further expanded the use of these flaps, so that they provide coverage as well as sensibility.
Little flap - neurovascular island flap.
- Restoration sensation - re-pulp, end-Joyn.

- Tenuous dissection
- Open entire palm
- Risk of nerve injuries (cold intolerance & paresthesia)
Venous system

Venous flaps also appeared "on stage" and found admirers. Pedicled or microvascular venous flaps have been described with success by some authors, but have not been universally accepted (7,8,18,46,69,74).

Classification of flaps:

There are several ways to categorize the various flaps. They can be classified according to:

Vascular anatomy
Perfusion pattern
Method of utilization
Localization of the donor site
Tissue components

Flaps are generally divided into random pattern flaps and axial pattern flaps. The credit of this classification has to be given to Mc Gregor (42) who first summarized the accumulated knowledge in a synopsis of flap perfusion patterns. A more detailed description based on extensive perfusion studies was given by Taylor (54). The earliest report of the use of local skin flaps was by Zeller (74) in 1810, who used a triangular lateral digital flap for syndactyly release. This flap can still be used to cover skin deficits after release of Dupuytren's contracture. The term "axial flap" was coined as early as 1917 by the dutch surgeon Esser who used this principle in facial reconstruction (15). The opportunities for these types of flaps have not been recognized until Littler (37) reported his digital transposition based on a neuro-vascular island pedicle.

Because of the vascular network described above, flaps can be proximally or distally based. Proximally based flaps are called antegrade flaps. Flaps that are nourished
- Common neurovascular flap - very important in intrinsic flap design. (Reverse flow flaps)
- Must include the nerves of the intrinsic muscle to preserve the vessels.
- More common radial side of the hand.
  Leave a strip of subcutaneous fat (contains venous outflow) tends to be bulky.
- Better than X-finger flap because you can start earlier from exercise.
- Skin graft the donor site when necessary - use thick skin graft (STSG)
- Can close a defect >1.8 cm wide

Reliable
Wide arc of rotation
Straightforward dissection
Skin graft often needed at donor site
Doppler examination
Somatic venous congestion (/10 flaps x 3 day)
Rare tendon adhesion
Good aesthetic result.
by distally based flow are retrograde flaps. Most of the recently described flaps are pure axial pattern types or at least have inflow from an axial vessel into a dense subdermal network as the "cross-finger" and "reverse cross finger" flap. Composite flaps can be raised on these vessels. The most recent extension of this concept are the extended DMCA (Dorsal Metacarpal Artery) flaps, which do not use the dorso-palmar perforator vessels at the level of the metacarpal head, but use a further distal perforator at the level of the proximal phalanx. These flaps are distally based and reach the dorsal fingertips from the proximal metacarpus (Fig. 2).

For this article we prefer a classification according to the vascular anatomy, the perfusion pattern, and the localization of the donor site.

**Indications - Flap selection**

Careful selection of the flap procedure is decisive for flap survival and the functional and aesthetic outcome. Many aspects have to be considered such as the choices available in the injured hand, the personal profile of the patient, the patient's concerns, and the surgeon's familiarity with the flaps.

The flap selection is based on:

- defect size and characteristics
- the requirements for sensibility
- technical difficulty
- the confirmation of the integrity of the vascular axis of the selected flap.
Kite flap -
  indication
  - restoration of sensation (pulp of
    thumb)
  - defect reconstruction
    - thumb,
      - dorsum of hand
    - 1st web space.

  - acting more lateral & radial (not
    really on dorsum)
  - + tunneling (controversial)

  - Reliable
  - wide arc rotation
  - penrose flaps
  - acceptable aesthetics
It should be understood that the choice of a sophisticated procedure has to be weighed against other options from the reconstructive ladder such as skin grafts. An optimal solution is considered a flap which meets the requirements of the defect with an acceptable donor site morbidity.

**Contraindications**

Certain injury patterns are contraindications for the use of intrinsic flaps if potential flap donor sites have been traumatized. Injury mechanisms that render flaps unreliable are:

- crush-avulsion
- wringer injuries
- high energy trauma, such as gunshot wounds
- previous history of lacerations that may have included arterial injury

**Complications and Treatment of complications**

Although the intrinsic flaps haven proven to be very reliable, there is still room for many potential complications. These include planning errors as:

- inadequate arc of rotation
- inadequate flap size
- vascular insufficiency after insetting (arterial or venous)
- donor site problems (take of skin graft, exposure of tendons, joints, or nerves,
- impaired digital perfusion
- total flap failure
Inadequate arc of rotation can usually be avoided by experience in planning and adding 10-15% more length so that the pedicle will not be stretched or twisted. This is also true for flap size. Vascular insufficiency on the arterial side frequently results from tunneling, short pedicle and tight wound closure. Venous congestion is similar to arterial in etiology, but kinking of the pedicle may be more dangerous to the venous outflow. Treatment includes suture release, hand elevation and sometimes leech therapy. Arterial insufficiency often requires remobilization of the pedicle, replacing the flap to its original position, or conversion into a microvascular free flap. In cases of flap failure it may be not prudent to use another intrinsic flap, and alternative solutions should be considered.
Metacarpal flaps

The first author who used an axial pattern flap from the dorsum of the index finger was Hilgenfeldt (23) who employed the flap in thumb reconstruction. Later Holevich (25) and Foucher and Braun (17) refined the concept by narrowing the pedicle until finally a true island flap based on the first dorsal metacarpal artery was developed.

The second dorsal metacarpal artery did not enjoy the same popularity: First experiences were published by Vilain and Dupuis in 1973 reporting their 20 year experience (70). Iselin also published this flap in 1973 (29). Both flaps were raised on the dorsum of the middle phalanx. The first true second dorsal metacarpal artery flap was the flag flap by Lister (38), which was actually a flap including either the dorsal metacarpal artery or the proximal dorsal branch of the proper digital artery. The flap has only a limited arc of rotation, but proved to be very useful in defects of the web space and the proximal phalanx. This flap used a perforator branch between dorsal and palmar system frequently found in the web space (75).

The dorsal metacarpal arteries predominantly follow a course within the fascial layer overlying the interosseus muscles. Inclusion of the fascia into the pedicle is mandatory to secure viability of the flap. Dorsal metacarpal flaps can therefore be classified as fascio-cutaneous flaps (Fig. 2). At the level of the metacarpal head, the dorsal network communicates with the superficial arch via constant anastomoses. These anastomoses form the basis of the reverse metacarpal flaps (41,52) which have further enhanced the versatility of this arterial system. More communicating vessels are found in the web space and the proximal phalanx thereby creating new options of flap design.

Antegrade metacarpal flaps

The presence of the dorsal metacarpal arteries is decreasing from the radial to the ulnar aspect of the hand. The fourth dorsal metacarpal artery may be missing in 17-30% (13). Therefore, Doppler examination prior to flap elevation is mandatory.

The first dorsal metacarpal artery flap in all modifications ("kite flap", "snuff box flap" etc.) has proven to be useful in the restoration of sensation of the thumb (12,13,17,19,28,73). The pedicle usually reaches the distal tip of the thumb. Protective sensation is good and recent follow-up studies revealed excellent cognitive sensibility (63,73). The donor defect is acceptable to most patients and is rather inconspicuous when the paratenon has not been injured during flap elevation and the skin graft is properly applied (Fig. 3a-d, 4).
Fig. 3a: Cavernous heangioma of the pulp of the thumb with severe tissue destruction
Fig. 3b: Intraoperative situs with both proper arteries skeletonized and resection of the heangioma
Fig. 3c: Reconstruction with a pedicled "kite" flap from the dorsum of the index finger
Fig. 3d: Perfect contour of the thumb after healing of the flap and skin grafting of the nailbed. Sensitivity was evaluated with the Semmes Weinstein test and demonstrated a value of 3.8 (high normal level).

The second dorsal metacarpal artery flap can be raised as a single lobe flap or can be raised as a bi-lobed flap using the branching vessels in the web space (12,13,31,49). The arc of rotation of all dorsal metacarpal flaps allows for coverage of proximal defects of

Fig. 4: Pulp of the thumb that 12 months after reconstruction with a pedicled "kite" flap following a severe trauma with IP
adjacent fingers and of smaller defects of the dorsum of the hand or the wrist area (Fig. 2).

Avoiding the technical pitfalls of the dissection makes these flaps a very reliable tool in reconstruction of smaller defects. The ability to provide sensation (based on branches of the superficial radial nerve) and the ease of dissection makes the first dorsal metacarpal island flap ("kite flap") comparable to the neuro-vascular island transfer described by Littler without sacrificing a proper digital artery.

A most recent variation of the old "seagull" flap was reported by Kojima(33). He used the web space branching of the dorsal metacarpal arteries to raise dorsal web space flaps with a digital extension to release web space contractures.

Reverse metacarpal artery flaps(12,41,52)

Anatomical studies by Early(11) and others(40,50) have demonstrated constant arterial anastomoses between the dorsal digital network and the superficial palmar arch at

Fig. 5a (above): Aesthetic result of an antegrade metacarpal flap from the long finger to the dorsum of the index finger.
Fig. 5b,c (left side) Function of reconstructed and donor finger. Schematic drawing of the reverse axial digital island flap and its arc of rotation
the level of the metacarpal heads. The reverse metacarpal artery flaps have been developed based on these findings\(^{(12,41,52,57)}\).

The reliability of these flaps also depends on the inclusion of the muscle fascia overlying the interosseus muscles. The distal pedicle can be identified when it dives deep into the web space. The flaps can be rotated 180° and reach the web space and the palmar and dorsal aspect of the proximal phalanx. Care has to be taken to include as many subcutaneous veins as possible into the pedicle to avoid venous congestion. Ultrasound examination is also mandatory in reverse metacarpal flaps to confirm the presence of a dorsal metacarpal artery.

Donor site morbidity of dorsal metacarpal flaps is low compared to axial digital island flaps. Neuromas are rare and the patients report less cold sensitivity than in digital flaps (Fig. 5a-c).

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**Fig. 6a** Design of an "extended digito-metacarpal flap" to cover a distal defect of the index finger. The flap is based on a perforator vessel at the level of the distal proximal phalanx.

**Fig. 6b** The flap after several days. The decision to graft the pedicle was made intra-operatively, since the subcutaneous tunnel lead to a constriction of the pedicle.

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"Extended DMCA flap- Digito-Metacarpal flap"\(^{(9)}\)

Further refinements have enhanced the therapeutic spectrum of the DMCA flaps. The arc of rotation can be significantly enlarged by using a perforator vessel in the web space or in the proximal phalanx as the distal base of the flap. This vessel also forms the base of the midphalangeal island flap, and feeds the subcutaneous arterial network. Inclusion of the dorsal metacarpal artery and the interosseus fascia into the pedicle is recommended. The inter-tendinous connections have to be divided in
some instances, and should be repaired after flap transfer. To secure venous outflow, a strip of 1cm of subcutaneous tissue should be included. Flaps based on these distal perforators easily reach the dorsal of the fingertips, nailbed, or the distal lateral aspect of the digits (Fig.6a,b)

**Special flaps**

**Free "kite" flap**

The first dorsal metacarpal artery flap can also be raised as a micro-vascular free flap for use in the contralateral or ipsilateral hand. We have successfully used this flap in four cases and it has become one of our favorite choices, when small free flaps are required (19). A modification of the pedicle "snuff-box" flap has been used as a microvascular flap to cover donor defects of wrap-around flaps (65).

**Flaps in the digits:**

Most recently developed digital flaps are situated at the dorsum and the lateral aspect of the finger. They can be divided into:

- Antegrade axial dorsal flaps
- Reverse axial dorsal flaps
- Antegrade axial lateral flaps
- Reverse axial lateral flaps
- Modified cross-finger flaps
- Palmar subcutaneous flaps
- Pedicle venous flaps

The skin flaps from the dorsum of the proximal phalanx based on a dorsal
Dorsal flaps

Antegrade axial flaps

Direct flow proximal island flap
Digito-metacarpal flaps

Reverse flow dorsal flaps

Reverse flow dorsal flap
Reverse dorsal digital island flap
Reverse distal dorsal island flap
Adipo-fascial turnover flap

Dorsal flaps are based on the dorsal arterial network which lies in the subcutaneous plane above the paratenon. This network has numerous communications with both palmar digital arteries. The distal part of this network is supplied by the distal dorsal branches of the palmar arteries while the more proximal part stems from the vanishing dorsal metacarpal arteries. The palmar-dorsal branches have been investigated by numerous authors and arise from the middle of the proximal phalanx, close to the PIP joint, and the mid-portion of the middle phalanx.

Antegrade axial flaps

Direct flow proximal island flap

This flap is based on the dorsal branch rising dorsally immediately before the PIP joint. This vessel also serves as the supplying vessel for Büchler's midphalangeal flap (Fig. 7). Although anatomic variations occur in vessel diameters, the vessel location is constant. The arc of rotation is limited to the

Fig. 7: Schematic drawing of several variations of antegrade axial flaps (With permission from 20a)
palmar surface of the PIP joint. Indications are skin deficits after contracture release or defects after traumatic flexor tendon lesions.

**Digito-metacarpal flaps**

These are extensions of the dorsal metacarpal flaps onto the dorsum of the digits, preferably the index or long finger. The level of dissection is above the paratenon with inclusion of the dorsal digital arteries and the interosseus fascia. The arc of rotation can reach the "knuckle area" and most of the distal metacarpus.

**Reverse flow dorsal flaps**

**Reverse dorsal digital island flap**

This flap is a true reverse pedicle flap and is based on the dorsal arterial network. To ensure that the arterial inflow is sufficient, a wide strip of subcutaneous tissue has to be included into the pedicle. Due to the termination of the distal dorsal metacarpal arteries, the flap should not extend further proximal than the middle third of the proximal phalanx. The arc of rotation can be 180° and the flap can reach the distal dorsal finger including nailbed injuries. These flaps are logical extensions from Iselin's concept of a reverse flag flap in the distal finger.

**Reverse distal dorsal island flap**

Tsai (1996) and Shibu (1997) described a small island flap based on the most distal palmar-dorsal perforator, the superficial arcade just proximal to the nailbed. The flap can be rotated 180° to reach the fingertip. The donor site has to be grafted. This flap is suited for the sensate reconstruction of smaller fingertip defects.

**Reverse flow dorsal flap**

The flap described above as an antegrade axial flap can also be based on a more distal pedicle. The authors define this type of flap as a "reverse flow flap". Since it is not defined if the communicating branch receives its supply only from retrograde flow in the palmar artery, the flap is rather a reverse pedicle flap with an undefined perfusion pattern. Its arc of rotation reaches the distal middle phalanx at the dorsal as well as the palmar aspect.

This flap is very useful at the dorsal aspect of the thumb, where it can be based on one of three dorso-palmar perforators from the proper digital arteries.
Adipo-fascial turnover flap\textsuperscript{(65)}

The flap has been described by several authors\textsuperscript{(5,66)} as a random pattern flap which requires a wide pedicle and a broad "safety turnover zone" to guarantee a sufficient number of perforators included in the pedicle. Inclusion of a defined artery or an arterial network makes this flap a true axial pattern flap. We found this flap not to be very reliable in coverage of digital defects but these are only anecdotal observations. However we would hesitate to recommend this flap in injured digits.

Lateral flaps

Antegrade axial lateral flaps:

- Digital island flap
- Reverse thenar flap
- Digital island cross-finger flap
- Midphalangeal island flap

Digital island flap\textsuperscript{(2,37,54,69)}

The antegrade neuro-vascular digital island flap has long been known for sensate reconstruction for the thumb pulp and is usually taken from the radial aspect of the ring finger or the ulnar aspect of the long finger\textsuperscript{(2,37,54,69)}. Antegrade axial flaps require an intact contralateral digital artery. They can be used even if the distal communicating arch in the pulp is destroyed or occluded (Fig.7).

By sparing the nerve during dissection, this flap can also be used as a septo-cutaneous flap to reconstruct complex defects at the dorsum of the finger\textsuperscript{(3,52)}.

Fingertip injuries can also be reconstructed with the antegrade island flap by mobilizing the pedicle similar to the flaps of Hueston, Moberg, and Tsai\textsuperscript{(27,43,68)}. This flap is called a direct digital island flap by Brunelli\textsuperscript{(9)} and reaches the fingertip as a sensate island flap in complex distal fingertip injuries.
Reverse thenar flap

The skin island of this new flap is based on perforating branches also nourishing the tuberositas of the scaphoid. The flap can be harvested as a free flap including a branch of the radial nerve or can be used as a reverse pedicle flap based on the proper radial artery of the thumb. Sensation can be restored by reconnecting the radial nerve to the proximal stump of the digital nerve.

Antegrade cross-finger island flap\(^{(34)}\)

If a conventional cross-finger flap cannot be raised and there is no homodigital solution for the particular defect, the antegrade arterial island flap can also be used as a pedicled cross-finger island flap to cover palmar or dorsal defects. Indications are rare but except the sacrifice of a proper palmar artery, the donor defect is inconspicuous and early active exercise with buddy taping is possible. The technique of flap elevation is identical to that of the homo-digital island flap. Separation of the pedicle is performed after 2-3 weeks.

Inclusion of a dorsal vein may be indicated in selected cases to improve venous outflow in segmental defects\(^{(34)}\).

Mid-phalangeal island flap\(^{(4)}\)

This flap is a modification of an axial island cross-finger flap and is based on dorsal branches of the proper digital arteries. The branches that communicate with the dorsal subcutaneous network take origin from the middle of the proximal phalanx, close to the PIP joint, and the mid-portion of the middle phalanx\(^{(4,6,11)}\). Venous drainage is provided by Vv. comitantes but a larger subcutaneous vein can be included into the pedicle depending on the flap design. A branch of the dorsal digital nerve can also be included.
Reverse axial lateral flaps

- Reverse arterial island flaps (Fig. 8)
- Reverse arterial cross-finger island flaps
- Reverse axial latero-dorsal flaps of the thumb

Fig. 9a: Distal defect over the PIP joint with exposed extensor tendon. A reverse homodigital island flap is already dissected and ready to be transposed into the defect.
Fig. 9b: Aesthetic result after 3 months. There is only a little contour deformity at the donor site.

Fig. 10a: Severe destruction of the DIP joint of the ring finger. Primary joint fusion during revision. Defect coverage with a reverse homo-digital island flap.
Fig. 10b: Aesthetic result after 6 weeks with a remaining nailbed deformity.
Reverse arterial island flap\(^{(5,24,54)}\)

This flap is based on retrograde perfusion from the contralateral digital artery via the distal communicating arch\(^{(5,32,56)}\). Its arc of rotation reaches more distally than the antegrade pedicle and is therefore suited to cover defects over the DIP joint or the fingertips (Fig. 9a,b, 10a-c).

Reverse axial cross-finger island flap\(^{(20,35)}\)

There are rare complex distal defects where the condition of the injured digit does not allow the elevation of conventional cross-finger flaps or reverse-flow homo-digital flaps. These are the indications for the reverse cross-finger digital island flap which was most recently described either as a sensate flap or a conventional septocutaneous flap\(^{(20,35)}\). We prefer to wrap a split-skin graft around the pedicle to avoid desiccation of the pedicle. The post-operative management is extremely important to prevent kinking of the pedicle and venous congestion (Fig. 11a-c).
The tendency towards a slight venous congestion is more pronounced in our experience in cross-finger flaps than in reverse homo-digital flaps. Very little is known about donor site morbidity in arterial island flaps. Increased cold sensitivity and changes in sensibility in the donor fingers was found in our group of reverse-cross finger flaps\(^\text{(20)}\). Therefore these flaps are "last resort" flaps in the spectrum of intrinsic hand flaps.

**Reverse pedicle island flap\(^\text{(47)}\)**

Another reverse flow island flap with a relatively small arc of rotation has been described by Niranjan and Armstrong\(^\text{(47)}\). They also use the proper digital artery, but try to center the skin flap over the defined dorsal communicating branches. In the thumb the flap can be based on the dorsal arterial network without severing the palmar artery.

**Dorso-lateral flap from the distal thumb\(^\text{(30)}\)**

This flap has already been described in 1974 by Joshi\(^\text{(30)}\), but never gained widespread popularity. It is based on the radial palmar artery and includes a branch of the dorsal radial nerve. It may be possible to raise this flap based on the dorsal arteries, but these vessels are more inconstant in the thumb than in the long fingers so that only few personal communications exist about this flap.

**Modified cross-finger flaps**

- **C-ring flap**
- **Distally based axial cross-finger flap**

The time honoured cross-finger flap has recently experienced several modifications to enhance its versatility.

**C-ring flap\(^\text{(45)}\)**

The C-ring flap is an either proximal or distally based flap which comprises the semicircumference of the digit. It can be used to cover larger complex defects in the distal middle phalanx, but its arc of rotation is limited due to the short pedicle.

**Distally based axial cross-finger flap\(^\text{(14)}\)**
This flap has a similar design to a conventional cross-finger flap but the inclusion of a unilateral digital artery makes it a "reversed" island flap in the distal finger. The flap can be used for dorsal or palmar distal defects, but also has only a limited arc of rotation. Major drawback of this flap is the sacrifice of a digital artery, whereas the enhancement of the arc of rotation is the advantage of this new technique.

**Pedicle venous flaps**

This flap was reported by Fukui et al. in 1989 but the design of the pedicle venous flaps raises considerable doubts about the vascular pattern. The description of the authors and the schematic drawing lead to the conclusion that this flap is rather an axial dorsal arterial flap including two draining veins than a true pedicled venous flap. The authors hesitate to recommend this flap as a safe routine procedure. With increasing experience, microvascular arterialized venous flaps have proven to be more reliable.

**Palmar flaps**

A new flap from the palmar side has recently been published by Voche and Merle (71). They demonstrated in anatomical studies the vascular supply of the palmar subcutaneous tissue and used this layer as a turn-over flap to cover dorsal defects (72). This new flap has definitely some potential but it requires very delicate dissection to preserve the paratenon of the flexor tendons and to avoid injuries to the neurovascular bundle.

**Interosseus muscle flaps / Segmental bone grafts**

With increasing knowledge about the dorsal arterial network, blood supply to the metacarpal bones and interosseus muscles has been elucidated. This lead to the development of interosseus muscle flaps and use of segmental metacarpal bone grafts in select cases (24). However the use of an interosseus muscle flap has to considered carefully since extension lag of the DIP and PIP joint might be a possible donor side effect.
Transverse dorsal metacarpal V-Y flaps

The newest development in flap design is the transverse dorsal metacarpal V-Y flap by Onishi and Maruyama\(^{(48)}\). The use either proximal or distally based V- flaps which include a dorsal metacarpal artery in the pedicle. The authors report 5 cases with considerable size defects without any complication. Although they do not refer to technical details, it has to be presumed that including the underlying interosseus fascia is a vital part of the dissection. All donor defects could be closed primarily.

Rehabilitation

The use of intrinsic hand flaps facilitates hand rehabilitation because by definition vascularized tissue is transposed into areas of need. In most cases motion can be started after flap viability is assured and wound healing begins, usually within 48 to 72 hours. Dynamic follow-up regimen after tendon repair also start at this time. Donor areas (such as in hetero-digital island flaps) that are covered with skin grafts, should be moved as soon as graft take is confirmed to avoid donor digit stiffness.

Conclusion

Many exciting options have been added to the armentarium of flaps in the hand in recent years. To secure optimal results sound knowledge of the anatomy is mandatory. Many factors influence the flap choice and as the Romans already knew "Many ways lead to Rome"- However we are able today to reflect the patient's concerns, donor site morbidity, technical difficulties of the flap, the choices available and still be able to select the optimal choice for a particular situation. Although the reservoir of innovations seems to be exhausted, we are sure that further refinements are "in the pipeline" that will further enhance our treatment options.
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Alternative hand flaps for amputations and digital defects

Traumatic or thermal injury to the hand may result in a composite tissue loss. Exposed tendon, bone, or joint surface is best treated by flap coverage. This paper will discuss four types of alternative hand flaps that can be used to treat difficult areas and/or minimize complications. (1) A thumb flap elevated from the metacarpophalangeal joint flexion crease covers a fingertip injury and the donor site is closed primarily. (2) A proximally based side-finger flap, preferably from the ulnar side of the donor finger, can be used to cover a fingertip defect in a young person or a thumb tip in any age. (3) A deepithelized cross-finger flap, flipped 180 degrees upside-down, can cover a defect on an adjacent finger. The under side of the flap and the donor area are skin grafted. (4) A proximally based arterialized side-finger flap, including the digital artery but sparing the digital nerve, is rotated dorsally to cover a secondarily exposed proximal interphalangeal joint in burn patients where adjacent fingers are not available as donor sites.


Traumatic or thermal injury to a digit often results in extensive tissue loss. Skin grafts applied to a soft tissue defect over exposed tendon, bone, or joint surface are usually unsuccessful or nondurable. Flap coverage of such injuries is preferable.

Many flaps have been described to cover composite digital defects. Kutler described advancement of V-shaped flaps with a Y closure, and Atasoy et al. used a single volar advancement flap to repair fingertip amputations. Littler and O'Brien advanced distally a volar neurovascular island pedicle flap based on both digital neurovascular bundles to cover the tip. Cross-finger flaps from the dorsal surface of an adjoining finger have been reported by many, as have flaps from the thenar eminence.

Digital tip or dorsal avulsion injuries have been covered with distant flaps from the chest, abdomen, groin, or opposite arm.

Repair techniques which borrow tissue from a noninjured area to cover a defect, are not without complications. Prolonged immobilization, usually in a flexed position, can lead to stiffness of the injured and/or the donor digit. Hyperpigmentation and depression are common to a donor site on the dorsum of a finger or palm. A palmar skin graft may be tender. Trauma involving multiple digits or a burned hand may not leave the usual local donor tissue available for flaps. Areas such as the thumb tip or the dorsum of a digit can be technically difficult to treat with conventional flaps.

Case reports and Methods

We have used four types of alternative local flaps to minimize complications and/or to treat difficult coverage problems. Specific injuries for which these flaps are designed include: (1) thumb tip or fingertip loss, (2) dorsal avulsion of digital tissue, and (3) dorsal exposure of the proximal interphalangeal (PIP) joint in a burn patient, following skin graft breakdown.

Thumb metacarpophalangeal flexion-crease flap. The radially based flap is elevated from the metacarpophalangeal (MP) joint flexion crease of the thumb (Fig. 1). It can be made 1 to 2 cm in width and as long as 3 to 4 cm. The flap easily reaches the tip of the index or long finger, and in some patients it reaches the ring or little finger. The donor site can be closed primarily in a straight line, avoiding a palmar skin graft or extensive scar. Less flexion of the injured finger is required than with a standard palmar flap.

Three patients, 6, 13, and 30 years of age had a fingertip deformity or injury reconstructed with a thenar-crease flap. The index finger was involved in two cases and the little finger in one case. All flaps survived, and full range of motion of both the injured finger and the thumb was retained. The donor sites were excellent in appearance and without pain in all patients.

Side-finger flap. A flap from the side of the donor finger can be used to cover an amputated thumb tip or a fingertip...
Fig. 1. Thumb flap is radially based and raised from MP joint flexion crease. Donor defect is closed primarily.

The flap is based proximally, centered on the mid-lateral line, and elevated from the side of the proximal segment of the donor finger. It can be rotated as much as 90° to cover a tip defect (Fig. 3, A and B). The donor site can be closed primarily or with a split- or full-thickness skin graft. When possible, the ulnar side of the donor finger should be used to avoid the radial tactile surface of the donor finger and to minimize deformity. The ulnar side of the finger is hidden from view during most hand use, making the donor site much less apparent and often imperceptible when closed (Fig. 3, C). The flap provides excellent cover for a thumb or fingertip amputation (Fig. 3, D). An injured finger, however, must be immobilized in marked flexion, making this method of fingertip reconstruction advisable only for young adults or children.

Five patients 13 to 42 years of age had side-finger flap reconstruction—four for a thumb tip amputation and one for avulsion of a long fingertip. The donor area was closed primarily in two patients and skin grafted in three patients. The flaps were raised from the ulnar side of the index finger for the long fingertip amputation and from the radial side of the long finger in the four thumb tip repairs. However, preference should be given to the ulnar side of the finger if possible. All flaps survived, and there was no residual loss of motion of the thumb or the donor finger.

Upside-down cross-finger flap. A modification of the standard cross-finger flap is the deepithelized upside-down cross-finger flap to cover dorsal digital defects (Fig. 4). A standard cross-finger flap from an adjoining finger is deepithelized with a scalpel (Fig. 5, A). The flap is then elevated in the standard fashion, leaving the peritenon of the extensor mechanism intact, and flipped 180° upside-down, to cover the dorsal defect of the injured finger (Fig. 5, B). The donor area and the undersurface of the flap are then covered with a thick split-thickness skin graft (Fig. 5, C), which does not minimize donor site deformity but does provide local skin and subcutaneous tissue cover for the dorsal surface of a digit which otherwise would require use of a distant flap (Fig. 5, D). Deep dermal deepithelization is required to prevent formation of epidermal inclusion cysts. A volar upside-down cross-finger flap can also be turned from an adjoining finger to cover an exposed flexor tendon.

Five patients 5 to 57 years of age had a single upside-down cross-finger flap used to repair defects on the tip of the thumb in one patient, the dorsal surface of the index finger in one patient, and the dorsal surface of the long finger in two patients. The fifth patient sustained third- and fourth-degree burns on the dorsum of the hand and fingers, with lesser burns
Fig. 3. A and B. A, A 13-year-old girl with dorsally directed fingertip amputations of index and long fingers. B, Tip defects covered with a thenar crease flap and a side-finger flap.

Fig. 3. C and D. C, No donor site deformity is visible on the dorsum of the hand following use of the side-finger and thenar crease flaps. D, Final result 1 year later, with good fingertip contour.

on the volar surfaces. The dorsum of the hand was successfully covered with a groin flap, the fingers were syndactylized, and the necrotic little finger was amputated at the PIP joint. Debridement of eschar on the volar surface of the proximal segment of the ring finger exposed flexor tendons. No dorsal skin was available for coverage, so an upside-down cross-finger flap was flipped over from the stump of the little finger to cover the bare tendons. All five flaps survived; however, in one patient half of the skin graft covering the donor site and the deep surface of the flap was lost to infection. This wound healed secondarily. Epidermal inclusion cysts requiring later excision occurred in two patients.
Skin Graft

Fig. 4. Upside-down cross-finger flap in cross-section showing flap flipped 180° with undersurface and donor area skin grafted.

Arterialized side-finger flap. Breakdown of a dorsal split-thickness skin graft in the healed burned hand may result in an open PIP joint. (Fig. 6, A). Infection usually results in destruction of the joint and/or loss of the finger. Adjacent fingers are not usually available as donor sites, and further skin grafts are not feasible. To preserve the joint and/or central slip, a proximally based, arterialized, side-finger flap from the lateral and volar surface of the involved digit can be elevated and rotated dorsally to cover the defect (Fig. 6, B to D). The flap incorporates the digital artery, leaving the digital nerve and perineural tissue intact. The venous drainage accompanying the artery and in the base of the flap is carefully preserved. After the donor site is darted at the volar flexion creases to prevent a straight line volar scar, it is covered with a full-thickness skin graft. A digital Allen’s test or doppler examination to determine the patency of both digital arteries is a prerequisite to prevent inadvertent devascularization of the digit or flap should one artery be nonfunctional. With the digital nerve intact, the donor site skin graft becomes reinnervated. The flap should be raised from the nondominant side of the finger when possible. The excellent vascularity of this flap aids in the resolution or prevention of infection and joint destruction.

The arterialized side-finger flap was used to cover five open PIP joints in four patients, ranging from 26 to 47 years of age. All flaps survived and successfully provided one-step cover of an open joint. There was no change in two-point discrimination on the tip of the donor fingers. Three patients showed mild-to-moderate decreased motion of four digits, due to joint or tendon injury prior to flap coverage. Two patients underwent reconstruction of the extensor tendon mechanism, which was accomplished without difficulty by reelevating the flap.

Discussion

Fingertip reconstruction using a thenar flap was first described by Gatewood and later popularized by Flatt.10 Proximally and laterally based thenar flaps requiring a donor site skin graft have been described. Smith and Albin used both a proximally and distally based thenar H-flap to create a closed system and avoid a palmar skin graft. When the flap is elevated from the MP joint flexion crease and the donor area is closed primarily, only a single straight line scar at the base of the thumb remains. Although some flexion of the thumb’s MP joint is necessary for closure, later stretching of the skin with use allows full extension. The finger is held in less flexion during the 12 to 14 days of immobilization than it would be if a standard palmar flap were used. The resultant scar is cosmetically acceptable and has not been painful in any patient.

Lewin and Tempest used a local rotation flap from the dorsal-lateral or lateral surface of the injured finger to repair a defect on the volar surface. MacDougal et al.17 used side-finger flaps to reconstruct the web space following the release of burn scar contractures. Curtis described a proximally based side cross-finger flap to cover a defect on the dorsal surface of an adjoining finger. Thumb tip cover from the dorsal-lateral surface of the proximal segment of the index or long finger has been reported by several authors.6, 7 In all cases, the donor area on the dorsal surface of the finger was covered with a skin graft. The donor site is much less visible, even when a graft is necessary to close the defect, when a proximally based side-finger flap on the ulnar side of the finger is used. The donor site may often be closed primarily. The resulting scar on the ulnar side of the proximal phalanx is not visible with the hand in a resting position. A side cross-finger flap from the proximal phalanx of the index or long finger provides an excellent cover for a thumb tip amputation in any patient. However, for fingertip trauma, the in-
Fig. 5. A and B. A, Index finger of a 14-year-old boy with an amputated distal phalanx and a dorsal avulsion injury to middle phalanx. Area of a standard cross-finger flap on dorsum of long finger is deepithelialized with a scalpel. B, Flap is elevated leaving peritenon intact and then flipped 180° upside-down over injured finger defect.

Fig. 5. C and D. C, Donor area and undersurface of upside-down flap are covered with a thick split-thickness skin graft. D, Final result 14 months later with excellent cover and function of remaining length of index finger.
Fig. 6. A and B. A, Healed burn patient with a secondarily exposed PIP joint following breakdown of a dorsal split-thickness skin graft. No adjacent fingers were available for flap transfer. B, Arterialized side-finger flap, incorporating radial digital artery and accompanying veins but sparing radial digital nerve, is elevated from just distal to distal interphalangeal joint flexion crease.

Fig. 6. C and D. C, Long arterialized flap is turned dorsally to cover exposed joint, bringing a generous blood supply to speed healing. D, Final result 3 months later, with durable skin and subcutaneous tissue over joint.
jured finger must be held in extreme flexion, making the technique useful only in the young or a patient with a very supple hand.

Buried dermal grafts have been used in a variety of ways from the creation of a static sling for facial nerve paralysis to replacing portions of Buck's fascia in the treatment of Peyronie's disease. The successful use of seven buried dermal flaps was described by Pakiam.19 Two of his cases were upside-down cross-finger flaps used to cover dorsal avulsion injuries over the PIP joint. Cyst formation did not occur in the finger cases but did complicate two local turn-over flaps whose bases remained undivided. Epithelial regeneration was attributed to the preserved blood supply in the base of the flap. In our series, two of four patients developed cysts despite division of the flap base. Deepithelization to the deep dermis should minimize this complication.

The breakdown of a split-thickness skin graft over the dorsal surface of a PIP joint in a healed burned hand has been a very difficult problem to treat. Good tissue on other digits is usually not available for flap transfer. The resultant open joint has been treated by fusion and grafting, covering it with a distant flap, or amputating the digit. The extensive scarring already present can cause necrosis of a nonarterialized flap long enough to cover the PIP joint. A well-vascularized axial pattern flap is created by the inclusion of the digital artery and its venae commitantes and by the protection of other subcutaneous veins at the flap base. The flap extends just beyond the distal interphalangeal joint flexion crease, preserving the pulp of the tip and its nerve supply. The full-thickness skin graft used to cover the donor site is darted at the flexion creases to prevent a straight line volar scar. The graft becomes rapidly reinnervated and minimizes contraction. The excellent blood supply of the arterIALIZED side-finger flap allows it to be reelevated for secondary procedures to the underlying joint or extensor mechanism and helps prevent or ameliorate existing infection.

Summary

A variety of local and distant flaps used to replace composite digital tissue loss has been described in the literature. The complications of using these flaps include deformity of the donor site, pain, and digital stiffness. Injuries such as amputation of a thumb tip or an open PIP joint may be difficult to treat with conventional flaps. Four types of alternative flaps which minimize complications and/or provide coverage for difficult digital defects are described. The methods and results using 18 flaps in 16 patients are discussed.

REFERENCES