Neurosensory Pedicled Flaps to the Hand

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Neurosensory is defined as being of or relating to afferent nerves [1]. For the purpose of this article, a neurosensory flap can be thought of as an innervated flap that provides sensory feedback, either immediately or after a neurorrhaphy. Incorporating a cutaneous nerve in a skin flap provides a means for sensory innervation and may aid the flap circulation because the skin vascularity partly depends on the vessels around these nerves [2]. Noninnervated flaps also may acquire some degree of sensibility through the ingrowth of peripheral nerve fibers, but often to a lesser degree.

Neurosensory flaps have special application to hand injuries [3,4]. Protective sensibility is desirable when providing soft tissue coverage of the dorsum of the hand and palm, but critical sensibility of the digits is important for functional hand use [5]. Moberg [6] stated that precision sensory grip or tactile gnosis requires 2-point discrimination of less than 6 mm, whereas gross sensory grip is possible at 6 to 15 mm. Pedicled neurosensory flaps have certain advantages over free tissue transfer. The arterial supply is often more reliable, which simplifies postoperative monitoring and lends itself to outpatient procedures. Finger flaps may be harvested from the same finger (homodigital) or an adjacent finger (heterodigital). Pedicled flaps may be antegrade or retrograde (reversed flow). Most of these flaps can be dissected under loupe magnification and permit early active motion, a desirable feature in acute injuries. Microvascular technique is helpful but not an absolute prerequisite.

Some general contraindications to pedicled flaps include any cause of massive hand swelling, such as crush-avulsion and wringer injuries, high-energy trauma, or prior arterial injury. Some pitfalls common to pedicled flaps include an inadequate arc of rotation, a short pedicle, vascular insufficiency due to tunneling, or inadequate flap size. It is good practice to add 10% to 15% more to the length and the size of the flap. Incorporating a small skin island along the vascular pedicle simplifies insetting and aids in avoiding skin bridges. Methods of salvaging a failing flap may include suture removal, leech therapy, or conversion to a free flap.

Myriad pedicled neurosensory flaps are described for fingertip and thumb coverage. Flap selection ultimately is based on the size of the defect; the requirements for sensibility; the surgeon’s comfort level; and the patient profile, including gender, age, and systemic disease. Knowledge of the skin topography and flap anatomy is integral to the success of any flap. The following discussion focuses on a select number of reliable and relatively easy to dissect flaps. Flap variations and typical sensory recovery are presented.

Hueston flap

The Hueston flap is a local transposition flap for fingertip skin loss that is pedicled on one neurovascular bundle. It was described by Hueston [7] in 1966 and subsequently modified by Souquet and Souquet [8] in 1986 to include both neurovascular bundles.
Anatomy

The flap is an asymmetrical arterial advancement flap based on either the radial or the ulnar neurovascular bundle. It relies on cutaneous perforators from the digital artery. The flap is drained by the venae comitantes and the intact subdermal venous plexus. It receives its innervation from the proper digital nerve. The advancing free edge of the flap is initially insensate, but regains sensibility with time. It has a range of advancement of 12 to 18 mm.

Indications

The flap is used to cover a loss of the pulp tissue of the fingers and thumb. It is indicated in situations in which it is important to preserve bone length to diminish the risks of a hook nail deformity and in which there is no possibility of distal replantation.

Advantages

The flap is homodigital and provides satisfactory texture for resurfacing fingertips. It is simple, it is reliable, and it allows immediate finger motion.

Limitations

The flap cannot be used with injury to a neurovascular bundle. It is not indicated when more than 18 mm of transposition is required.

Surgical technique

The skin is advanced on the side of relatively less functional importance, such as the radial pulp of the thumb and small finger or the ulnar border of the middle digits. An L-shaped incision is made proximal to the fingertip defect. The longitudinal limb extends along the midlateral line, while the transverse limb is placed in the metacarpophalangeal (MCP) or proximal interphalangeal (PIP) flexion crease. The plane of dissection passes superficial to the neurovascular bundle that is closest to the midlateral incision. The contralateral neurovascular bundle is incorporated into the base of the flap, which is advanced obliquely to cover the amputation stump. A proximally based triangle of skin raised along the longitudinal border of the flap can be rotated transversely to cover the donor site [9].

Variations

The flap can be modified by including both neurovascular bundles (Fig. 1). This modification was thought to preserve the sensibility of the flap, at the expense of restricting some distal advancement [8]. The longitudinal incision is made in the same manner as already described, whereas the transverse incision is extended to the opposite midlateral line, ending with a back cut. The plane of dissection proceeds deep to both neurovascular bundles, which are incorporated into the skin flap. The flap is advanced and inset as already described.

Sensory recovery

In Foucher’s series [9] of 43 flaps, 2-point discrimination averaged 7 mm in the standard Hueston flap (31 cases) and 6 mm with the modified flap (12 cases).

Complications

The palmar tension pulls on the nail matrix, which causes a tendency toward a parrot beak nail deformity. This tendency can be minimized by skewering the tip of the flap with a transfixing needle. The free edge of the flap can lead to a dog-ear deformity, which can be
corrected by excising a segment of dorsal skin. Cold intolerance is common during the first year and correlates with poorer return of sensation. Persistent fingertip sensitivity may occur secondary to neuroma formation. A contracture of the distal interphalangeal or PIP joint may result if there is excessive joint flexion during flap insetting.

Fig. 1. (A) Sideways view of modified Hueston flap for thumb coverage. (B) Note amount of advancement based on both neurovascular bundles. (C) A proximally based triangle of skin raised along the longitudinal border of the flap is rotated transversely to cover the exposed pedicles (asterisk).
Innervated cross finger flap

More than 50 years after its description, the cross finger flap is still widely in use [10]. In cases in which the dorsal digital networks cannot be used or when elaborate microsurgical procedures are not available, cross finger flaps are still useful for finger coverage distal to the PIP joint. Sensory return is unpredictable, however, and can mar the ultimate functional result. The innervated cross finger flap was developed to improve on this by transferring the dorsal skin over the middle phalanx along with its sensory nerve [11]. A neurorrhaphy is performed between this nerve and one of the severed digital nerve ends of the injured finger.

Anatomy

The initial blood supply of this random pattern flap comes from one of the paired dorsal branches arising from the palmar digital artery at the proximal one third of the middle phalanx [12]. The venous drainage is initially from the venae comitantes and subdermal veins. The superficial branch of the radial nerve (SBRN) and the dorsal cutaneous branch of the ulnar nerve innervate the dorsum of the hand up to the level of the PIP joints. Distal to this, the dorsal skin is innervated by a dorsal sensory branch that arises from the proper digital nerve. This branch most commonly arises proximal to the PIP flexion crease (see Fig. 2). It then crosses superficial or deep to the digital artery to lie just above the extensor mechanism, innervating the dorsum of the middle phalanx [13,14].

The arc of rotation of the cross finger flap is short because the skin is pedicled on the midlateral line of the finger. The flap is left attached to the donor finger until sufficient peripheral arterial and venous anastomoses have occurred, then it is divided.

Indications

The innervated cross finger flap is indicated in cases of full-thickness loss of the entire pulp of an adjacent finger, especially with exposed bone or tendon. The long finger is used for coverage of the thumb pulp.

Advantages

The cross finger flap is extremely reliable and easy to perform. It can be used for larger defects that may not be suitable for homodigital flaps. With the innervated flap, no additional donor finger denervation occurs because the dorsal sensory branch ordinarily is transected when

Fig. 2. Dorsal sensory branch arising from the proper digital nerve of the small finger. Asterisks show the dorsal cutaneous branch of the ulnar nerve.
elevating the standard cross finger flap. Suturing this branch to the transected digital nerve in the recipient finger allows reinnervation without any need for cortical reorientation.

**Limitations**

The innervated cross finger flap cannot be used when there is concomitant injury to adjacent digits. Flap innervation is not possible if there has been damage to either the dorsal sensory branch or the proximal digital nerve. Patients who are older than 40 years old are relatively contraindicated because of the finger stiffness that results from 2 weeks of immobilization to another digit [15].

**Surgical technique**

The dissection is performed under tourniquet control [16]. A pattern of the defect is outlined over the dorsum of the middle phalanx of an adjacent finger. Two transverse incisions delineate the proximal and distal extent of the flap. A longitudinal incision is made on the side opposite the injured finger. The incision should not extend volar to the midlateral line to prevent a scar contracture. The dorsal sensory branch is isolated through a separate proximal incision, which extends to the edge of the flap. The nerve is sectioned proximally, leaving a 1.5- to 2-cm tail. The flap is elevated along with the nerve branch. The plane of dissection proceeds superficial to the paratenon of the extensor mechanism. The flap is dissected laterally to the opposite midlateral line, until it can be transposed without acute angulation.

Next the digital nerve end is isolated along the opposite border of the injured digit. The tourniquet is released ensuring flap viability. A full-thickness skin graft is placed over the donor site and secured with a tie-over bolster. The flap is transposed and inset so that the deep surface of the flap lies against the finger defect (Fig. 3). An epineurial repair between the dorsal sensory nerve branch and the digital nerve is performed with 9-0 nylon suture. A finger spica splint or bulky dressing is applied to prevent tension on the suture sites. At the time of flap division 2 weeks later, no special care for the nerve repair is necessary because the nerve junction is on the side opposite the flap base.

![Fig. 3. (A) Fingertip saw injury. (B) Pedicled cross finger flap.](image-url)
Variations

Lassner et al [17] have used a bilaterally innervated sensory cross finger flap. First, the contralateral dorsal sensory branch is elevated with the flap at the PIP joint level and sutured to the digital nerve end on the far side of the injured finger. After 3 weeks, when the pedicle is dissected, the remaining dorsal sensory branch is dissected and sutured to the remaining digital nerve of the injured finger. Because the regenerative distance is only 1.5 to 2 cm, there is excellent sensory reinnervation, with 2-point discrimination ranging from 2 to 6 mm.

Gaul [18] described an innervated cross finger flap from the index that provides immediate sensation for resurfacing volar defects of the thumb. The flap is transferred along with the dorsoradial digital nerve to the index, which is a continuation of the major dorsal branch of the superficial radial nerve[19]. This sensory branch is mobilized at the same time the cross finger flap is transposed and transferred subcutaneously to lie under the volar skin envelop of the thumb.

In an effort to improve the ultimate sensibility, Hastings [20] modified this index finger flap by turning it into a dual innervated flap (Fig. 4). The superficial radial sensory nerve is mobilized and transposed as described earlier. The dorsal sensory branch of the proper radial digital nerve of the index is sutured to the severed end of the ulnar digital nerve of thumb. Sensory reinnervation is reported to be rapid and does not require cortical reorientation.

Sensory recovery

In one series of innervated cross finger flaps, seven of eight patients achieved an average 2-point discrimination of 4.8 mm compared with patients with noninnervated cross finger flaps, who achieved a mean value of 9 mm [16].

Complications

Joint stiffness is common. The flap may be hair bearing. Donor finger morbidity includes poor skin graft color match and a visible contour deformity. If only one digital nerve anastomosis is performed, a painful neuroma may develop from the unrepaired digital nerve stump.

The functional outcome of the radial sensory innervated cross finger flap is compromised in some patients by double sensitivity. In this case, sensation from the ulnar side of the flap is interpreted as arising from the dorsum of the index finger, whereas sensation on the radial side of the flap is interpreted as coming from the thumb. Sensory testing shows that after transfer to the thumb, the ulnar side of the flap still receives its innervation from the superficial sensory branch of the radial nerve [21].

Reversed digital artery flap

The reversed digital artery (RDA) flap, described in 1986 by Kojima et al [22], is used for one-stage reconstruction of finger pulp defects. The flap can be innervated by including the dorsal sensory nerve branch.

Anatomy

The RDA flap is harvested from the dorsolateral skin of the proximal phalanx, which derives its blood supply from the opposite digital artery through abundant communicating branches. There are three transverse palmar arches connecting the radial and ulnar digital arteries. The proximal and middle arches are always in association with the limbs of the C1 and C3 pulleys. The distal arch lies just beyond the insertion of the profundus tendon [23].

When the proximal digital artery is ligated, the blood crosses over from the opposite digital artery through the middle and distal transverse palmar arches. The blood flows down the ligated artery in a retrograde fashion (Fig. 5). The RDA flap is designed over the dorsolateral area of the proximal phalanx, which is nourished by a proximal dorsal cutaneous branch. This small
branch, 0.3 to 0.6 mm in size, arises from the palmar digital artery at the midpoint of the proximal phalanx (Fig. 6) [12]. It passes through Cleland’s ligament, running close to the bone, and emerges on the dorsal aspect of the finger. Histologic studies revealed the presence of venules and capillaries in the perivascular fat tissue, which appear to represent adequate channels for venous drainage [13].

The dorsal sensory nerve branch is harvested with the skin flap (see Fig. 2). In the border digits, the terminal branches of the superficial radial nerve or dorsal cutaneous branch of the ulnar nerve also can be transferred. The arc of rotation is around the midpoint of the middle
phalanx, which allows the flap to reach the fingertip easily. The digital artery cannot be elevated beyond the middle phalanx for fear of disrupting the distal transverse arch.

**Indications**

The RDA flap is indicated for coverage of acute and chronic fingertip defects. It can be used for fingertip reconstruction to correct a hooknail deformity (Fig. 7). Some authors recommend the RDA flap for coverage of large defects of the dorsal aspects of the middle and distal phalanx, which cannot be covered with other local digital sensory flaps (Fig. 8) [24]. It also may be useful after release of volar scar contractures of the fingers.

**Advantages**

This procedure provides a method for a one-stage reconstruction of finger pulp defects. It restores sensation with a good color match, while allowing early finger motion. The RDA flap has great mobility and transfers to the pulp defect without any tension when based on a reverse vascular pedicle. Neurorrhaphy between the dorsal sensory branch and the terminal digital
nerve allows for flap innervation through the normal anatomic pathway so that cortical misinterpretation can be avoided [13].

Limitations

A disadvantage of this procedure is that it sacrifices a digital artery, and a nerve repair is required. The RDA flap cannot be used if there is only one patent digital artery or if there has been an injury to the distal transverse palmar arch.

Surgical technique

A digital Allen’s test with or without Doppler is used to ascertain that both digital arteries are intact [25]. Under tourniquet control, the injured tip is débrided, and a pattern of the defect is outlined over the proximal phalanx. The flap margins are incised and elevated, including the subcutaneous tissue and the digital artery. The dorsal sensory branch is identified and divided 10 mm proximal to the flap margin. A midlateral incision is made from the distal flap margin, as far as the midpoint of the middle phalanx. The artery is separated from the digital nerve, leaving as much surrounding fat as possible for venous drainage.

A microvascular clamp is applied to the digital artery proximal to the skin flap, while the tourniquet is released to check the circulation of the finger and the flap. The proximal artery is divided and elevated to the midportion of the middle phalanx.

The skin island is rotated 180° into the fingertip defect, taking care to avoid kinking the pedicle. Leaving a tail on the flap or skin grafting the pedicle can avoid arterial compression. The dorsal sensory nerve branch is sutured to the recipient nerve before insetting. Donor site defects of 2 × 3 cm can be closed primarily. Flaps 5 × 2 cm can be harvested.
Variations

Lai et al [26] described an extended RDA flap in which the dorsal skin over the MCP joint may be included. This skin extension is a fasciocutaneous flap that survives on the rich anastomosis between the first dorsal metacarpal artery and the digital artery near the metacarpal head [27]. Lai et al [26] noted that the sensory recovery of this skin extension was relatively poor. In an effort to overcome this poor sensory recovery, the dorsal sensory branch from the proper digital nerve and the superficial sensory branch from the corresponding radial or ulnar nerve are sectioned at their proximal ends and included with the RDA flap (see Fig. 2). For bilaterally innervated flaps, these branches are sutured to both digital nerve ends. Static 2-point discrimination of 5 mm was obtained in Lai’s series of 3 patients [26].

In cases in which one of the digital arteries has been injured, an innervated RDA cross finger flap harvested from the proximal phalanx of the adjacent finger can be used to cover defects of the middle and distal phalanges. A piece of skin graft is placed over the pedicle, which is divided at 2 weeks [28]. In situations in which the fingertip pulp is lost completely, some authors have included the proper digital nerve in the pedicle, which is sutured to the stump of the opposite proper digital nerve [29].

Sensory recovery

Mean values for 2-point discrimination range from 6 to 10 mm [30]. Noninnervated flaps also have been reported to regain less than 10 mm of 2-point discrimination sensation [31].

Complications

Flap edema secondary to impaired venous drainage from kinking of the pedicle or an inadequate amount of perivascular fat for venous drainage is common. The flap tends to be bulky if applied over subcutaneous tissue rather than bone (Fig. 9). Skin grafting the pedicle at the distal interphalangeal joint may be necessary. Inadequate finger perfusion occurring when
the digital artery proximal to the island flap is clamped may preclude use of this flap. Numbness over the dorsum of the middle phalanx owing to transection of the dorsal sensory branch may be bothersome. If the margin of the flap extends volar to the midaxial line, a PIP flexion contracture can develop. Cold intolerance is a risk, especially for outdoor workers in cold climates.

Dorsoulnar flap of the thumb

The arterial supply of the thumb is different from that of the fingers. Direct or reverse flow volar island flaps centered on only one arterial pedicle, which have been described for the fingers, are not possible for the thumb. Through their anatomic studies, Brunelli et al [32] discovered a consistent artery along the dorsoulnar aspect of the thumb, which they used as the basis for a reverse pedicled skin flap. The flap can be innervated by incorporating the terminal branches of the superficial radial nerve and can be used for coverage of distal thumb defects.

Anatomy

The arteria princeps pollicis divides into two palmar digital arteries at the level of the MCP flexion crease. As a consequence, any pedicled flap of the thumb that is based on the palmar arteries has a short pedicle; this would require marked interphalangeal joint flexion to prevent undue tension on the princeps pollicis. The dorsal arteries of the fingers are extremely segmental, inconstant, and dependent on palmar anastomoses. In the thumb, there is a constant dorsoulnar artery, which originates from the palmar arteries at the neck of the thumb metacarpal and runs along the dorsoulnar side of the thumb. It may be 0.1 mm and travels superficially within the subcutaneous tissue, above the aponeurosis. A similar, but less constant and smaller artery may be found 72% of the time along the dorsoradial aspect of the thumb [33].

The dorsoulnar artery is reinforced by an anastomosis with the palmar digital artery at the neck of the proximal phalanx, approximately 2.3 cm from the nail fold. The artery terminates in a dorsal arcade within 0.7 mm of the nail. Venae comitantes can be present when the artery is of a large size (about 50% of cases). In the remaining cases venous drainage is based on tiny venules in the perivascular fatty tissue (Francesco Brunelli, MD, personal communication). The terminal sensory branch of the superficial radial nerve is located 1 to 2 cm from the median axis of the thumb.

Indications

The dorsoulnar flap is indicated for reconstruction of extensive loss of the thumb pulp. It can be used for coverage of amputation stumps at the interphalangeal joint level or for coverage of dorsal skin loss over the proximal and distal phalanx.
Advantages

The flap provides satisfactory texture for resurfacing fingertips and is homodigital, which allows immediate thumb motion. Because of the distal nature of its pedicle, the flap can reach the tip of the thumb easily. Primary closure of the donor site is possible for smaller flaps.

Limitations

The flap cannot be used with injury to the princeps pollicis or ulnar digital artery. It also is contraindicated when there is a significant soft tissue injury at the base of the thumb.

Surgical technique

The following points are marked first on the skin [34]: (1) the dorsal arcade of the proximal nail fold, 0.9 cm proximal to the nail base; (2) the palmar anastomosis at the level of the neck of the proximal phalanx, 2.5 cm proximally; and (3) the course of the dorsoulnar artery, 1 cm from the median axis of the thumb at the level of the neck of the proximal phalanx (Fig. 10). The flap dimensions are marked out on the dorsoulnar aspect of the MCP joint, centered over the dorsoulnar artery. The flap is raised in a proximal-to-distal direction. The terminal sensory branch of the radial nerve is located and divided 2 cm from the proximal flap edge. A midlateral incision is extended along the ulnar side of the thumb connecting to the distal area of soft tissue loss. This incision is superficial to avoid damaging the arterial pedicle. Two dermoeipidermis skin flaps are raised in a dorsal and palmar direction starting from the ulnar incision, taking care not to harm the subcutaneous tissue. A 1-cm-wide, full-thickness strip of subcutaneous tissue is harvested en bloc and centered around the arterial axis of the flap, leaving the extensor aponeurosis in situ. The flap artery may be quite small and is not directly isolated during harvesting to avoid damage. Care should be taken to avoid any tension or compression where the subcutaneous pedicle is reflected on itself.

The flap can be pedicled distally at two levels, which determines the arc of rotation. It can be pedicled at the dorsal nail fold arcade for cases of distal amputation or for loss of palmar or dorsal tissue. Dissection of the pedicle must be limited to 1 cm from the nail base. When used for more proximal amputation stumps, it is pedicled on the palmar anastomosis at the neck of the proximal phalanx. In this case, the dissection should be limited to 2.5 cm from the nail base.

Variations

The flap can be used as a cross finger variant for coverage of skin loss of the fingers. Any part of the hand is accessible to this flap based on the distal end of a mobile thumb [35]. The temporary pedicle, composed of a 1-cm-wide band of skin and subcutaneous tissue, is divided at 15 days after a clamping test confirms that the flap has become autonomous.

The dorsoulnar artery sends several periosteal and osseous branches to the neck of the first metacarpal. Vascularized bone from the metacarpal neck can be harvested with a reversed pedicled dorsoulnar skin flap for reconstruction of combined skin and bone defects of the distal phalanx [36].

Sensory recovery

Sensory recovery is disappointing, ranging from 10 mm to protective sensibility. In Brunelli’s series [32], there was no significant difference in sensibility between innervated and non-innervated flaps.

Complications

Raising the flap proximal to the MCP joint may exclude the nutrient artery, resulting in flap failure. Harvesting the terminal radial sensory nerve branch of the thumb leads to sensory loss.
over the dorsum of the thumb and could result in neuroma formation. Harvesting the skin from the dorsoulnar aspect of the thumb MCP can result in a restriction of MCP motion along with a decrease in the first web space span. The donor area is hair bearing, and debulking of the flap may be necessary because of overlap of the pedicle.
First dorsal metacarpal artery flap

The first dorsal metacarpal artery (FDMA) flap is a fasciocutaneous flap first described by Holevich in 1963 [37]. It was modified and used as a neurosensory island flap by Foucher and Braun in 1979 [38]. It is based on the FDMA or its dorsal digital branches. The flap is innervated by terminal sensory branches of the superficial radial nerve.

Anatomy

The FDMA arises from the radial artery just distal to the extensor pollicis longus tendon, before the artery dives between the two heads of the first dorsal interosseus (FDI) muscle (Fig. 11). The FDMA typically measures 1.2 to 1.5 mm in diameter. There is usually more than one accompanying vein. The artery runs superficial to the FDI fascia and divides into three terminal branches: a radial (FDMAr), ulnar (FDMAu), and intermediate branch. The radial branch runs along the thumb metacarpal and becomes or anastomoses with the dorsoulnar artery. The ulnar branch runs along the index metacarpal up to the MCP joint, giving branches to the periosteum and adjacent extensor tendons. It terminates in a plexus over the dorsal fascia of the index (Fig. 12). The intermediate branch runs toward the first web space and anastomoses with branches from the other two. The flap is based on either the radial or the ulnar branch of the FDMA. A proximally based flap is rotated around the point of origin of the artery at the base of the first dorsal interosseous space. The arc of rotation can include the palmar or dorsal thumb, wrist, and palm to the third metacarpal.

The venous drainage is that of the accompanying superficial veins. The superficial branch of the radial nerve becomes subcutaneous after it leaves the brachioradialis, then bifurcates into two major branches 4 cm proximal to the styloid [39]. Both branches pass radial to Lister’s tubercle. The major palmar branch passes over the first dorsal wrist compartment, then continues distally to become the dorsoradial digital nerve of the thumb. The major dorsal branch also bifurcates into the dorsoulnar digital nerve to the thumb and the dorsoradial digital nerve to the index, which supplies the adjacent sides of the second web space [19].

Indications

The FDMA flap is indicated for resurfacing either volar or dorsal defects of the distal thumb as far distal as the interphalangeal joint (Fig. 13). It can be used to cover the ulnar surface of the dorsum of the hand and the wrist or the palm up to the third metacarpal. The FDMA flap is useful for first web space reconstruction after contracture, and it can provide soft tissue coverage of the index finger up to the level of the proximal phalanx (see Fig. 13A–C).
Advantages

Advantages of this flap are its variable size, stability, and pliability. It provides innervated skin with no major donor site morbidity. Its elevation does not sacrifice a major artery. It can be transferred as a pedicled flap or an island flap. The innervated FDMA flap allows immediate postoperative mobilization and the avoidance of a nerve repair. It restores sensibility, particularly in older patients, in whom nerve repairs of a pedicle or free flaps yield poorer results than in younger patients [40].

Limitations

The flap cannot be used with radial artery injury in the snuffbox. If the skin overlying the first web space is included in the flap, skin grafting the donor site defect may lead to a secondary contracture. The arterial pedicle is difficult to dissect. The flap is at risk of partial necrosis if pedicled on a nondominant branch.

Surgical technique

Pedicled flap

A Doppler probe may be used to check the pulse of the FDMAr and FDMAu against the first and second metacarpals. The flap is drawn over the dorsum of the index, thumb, or back of the hand according to the skin defect. Under tourniquet, the flap is raised from distal to proximal, in the areolar plane over the extensor paratenon. The skin incision is continued along the radial aspect of the index metacarpal to include a large subcutaneous vein in the pedicle. At the second metacarpal neck, a large perforator is consistently present and should be ligated. The entire interosseous fascia over the FDI is included to avoid a meticulous dissection of the pedicle and to avoid raising the flap on a nondominant branch. A small cuff of muscle of the FDI may be included to ensure the artery is included in the pedicle. Either the palmar or the dorsal branch of the SBRN is incorporated into the flap. The fascia is released from the metacarpal until the flap can reach the defect. If the flap is used for first web space reconstruction, the interosseous fascia is released from the thumb and index metacarpals. The flap is enlarged ulnarly toward the third metacarpal so that the skin extension lies on the first web space, avoiding a first web space contracture [41].
Island flaps

The flap is pedicled on the FDMAu when used to cover defects over the volar surface of the distal thumb (Fig. 14) [42]. Alternatively the dorsal skin over the proximal phalanx of the thumb, which is supplied by the FDMAr, can resurface the radial side of the index. The flap is outlined over the dorsum of the index proximal phalanx. A proximal longitudinal incision is

Fig. 13. (A) Exposed plate after revascularization for partial hand amputation. (B) Flap based on the FDMAr. (C) Long-term result.
made over the FDI muscle. The flap is elevated starting distally, developing the plane between the subcutaneous tissue and the extensor tendon paratenon up to the level of the MCP joint. The dorsoradial branch of the SBRN is harvested with the skin island. The subdermal fascia can be quite thin; care is taken to preserve its continuity with the FDI fascia. Inclusion of a small strip

Fig. 14. (A) Saw injury to right thumb with destruction of the interphalangeal joint. (B) FDM flap raised from dorsum of index with a proximal skin tail. Note preservation of the continuity of the fascia (*) between the skin island and the interosseous muscle. (C) Insetting of flap after interphalangeal joint fusion. (D) Long-term result.
of extensor hood along the radial aspect of the extensor hood is recommended to protect the vascular connection from the pedicle to the skin island [43]. Flap dimensions extend from the base of the proximal phalanx to the PIP extension crease and can be $4 \times 2$ cm. The pedicle can be 9 cm in length.

The proximally based flap is rotated around the origin of the FDMA at the base of the first web space. It can be rotated and passed through a subcutaneous tunnel, taking care not to compress the pedicle at the thumb interphalangeal joint. Harvesting a proximal tail with the island flap simplifies insetting and avoids the need for tunneling (see Fig. 6). The donor site is skin grafted.

Variations

Harvesting the dorsal skin over the middle phalanx of the index as a random extension allows coverage of larger defects than a standard FDMA flap in a normal-length thumb [44]. Composite flaps include the extensor indicis proprius or communis tendon, which can be transferred as a vascularized tendon graft. An insensate fascial flap also may be used for soft tissue coverage only, but it requires skin grafting.

Reversed flow fascial flaps can be used for coverage of the dorsum of the digits proximal to the PIP joints [41]. This flap variant cannot be innervated. The reversed flow flap can reach as far ulnarily as the fifth metacarpal head. In this variation, the FDMA is ligated at its origin from the radial artery. The interosseous fascia is elevated up to the level of the metacarpal neck. The donor site is skin grafted if primary closure is not possible.

Sensory recovery

In one large series, the average 2-point discrimination was 10.8 mm (range 4–15 mm). There was no difference in patients younger or older than 50 years old. The average loss of 2-point discrimination over the flap area compared with the donor area was 2.7 mm [43].

Complications

Postoperative complications may include flap edema from kinking of the pedicle. Flap necrosis can occur with injury to the thin fascial extension between the index island flaps and the FDI. Numbness over the dorsum of the middle phalanx of the index or hair growth over the volar aspect of the thumb may be an irritation. Loss of index finger motion and poor take of the skin graft over the index extensor tendon are possible. Cold intolerance and dysesthesia can occur in 30% of patients [45].

Pedicled radial forearm flap

The radial forearm flap is a useful and versatile fasciocutaneous flap designed on the radial artery. Yang et al [46] initially developed this flap as a free flap in 1978. It subsequently was described as a pedicled flap using either antegrade or retrograde blood flow [47,48]. The flap includes the volar forearm skin, the underlying antebrachial fascia, and the intermuscular fascia, which contains the radial artery and its cutaneous branches. It can be innervated by the medial and lateral antebrachial cutaneous nerves. With retrograde flaps, neurorrhaphy to the local nerves is required.

Anatomy

The skin of the forearm flexor surface does not have any truly axial artery. An axial pattern flap in effect is created by raising a flap including the fascial and subcutaneous vessels with their longitudinal orientation and interconnections [49]. The entire radial artery from its brachial artery origin to the wrist can be transferred. For most of its course, the radial artery lies under the brachioradialis. The pronator teres, flexor pollicis longus, and pronator quadratus lie deep
to the artery. The SBRN is lateral to the artery under the brachioradialis. After giving off the radial recurrent artery near its origin, the radial artery has no named branches until it reaches the wrist. Here it gives off a superficial palmar branch and a palmar carpal branch. Cadaver studies have shown 9 to 17 branches from the radial artery to the fascia along the flexor surface of the forearm. The branches supplying the skin are contained in an intermuscular septum between the brachioradialis and the flexor carpi radialis (Fig. 15). These branches are arranged into a proximal and distal group with corresponding zones of perfusion [50]. In the distal half of the forearm, there are branches every 1 to 2 cm. As elsewhere, one vascular zone can be extended into another. The distal zone vessels can perfuse a fasciocutaneous flap as far proximal as the elbow. In a reverse pedicled flap, the skin blood supply depends on retrograde flow from the ulnar artery through the deep palmar arch.

Venous drainage of the radial forearm flap is by means of the superficial and the deep veins. There are three subcutaneous veins—the cephalic, basilic, and median forearm veins—and the paired deep venae comitantes of the radial artery. A reverse pedicled flap is drained by means of retrograde flow through the venae comitantes. Normally the venous valves prevent backflow. When a distally based flap is raised, the veins are denervated. The veins are kept filled by blood from the wrist and hand, which leads to increased venous pressure after ligation of their proximal ends. The combination of these factors allows reverse flow through the venous valves [50].

The SBRN, brachioradialis, flexor carpi radialis, and palmaris longus tendons are supplied by direct branches and branches off cutaneous vessels. The medial and lateral antebrachial cutaneous nerves enter the proximal margin of the flap and supply sensibility to the volar forearm.

The radial artery gives off at least two periosteal branches of 0.2 to 0.5 mm in size along the lateral aspect of the radius, immediately distal to the pronator teres insertion. These branches are accompanied by two small venae comitantes and pass along the fascial layer deep to the extensors carpi radialis longus and brevis. Musculoperiosteal vessels form a constant source of blood supply over the anterior aspect of the distal shaft. They are fed by branches of the radial artery supplying the flexor pollicis longus and pronator quadratus [51].

Over the distal volar forearm, the flap is thin with little fat, but it leaves a poor bed for skin grafting, consisting of tendons covered only by paratenon. A proximal flap is hair bearing and thicker because it has more subcutaneous fat. The donor site contains muscle bellies, which is more favorable for skin grafting. The skin can be innervated by including the medial or lateral antebrachial cutaneous nerve. The flap can include the entire volar forearm skin from the subcutaneous border of the ulna around to the radial dorsum of the forearm, extending as far proximal as the antecubital fossa. Forearm flaps measuring 35 × 15 cm have been reported.

*Fig. 15. Demonstration of cutaneous branches (*) arising from the radial artery (RA) coursing through the intermuscular septum.*
Indications

The flap is useful for thumb reconstruction (Fig. 16). It can be used for coverage of the palm or extensor surface of the carpus, with or without vascularized tendon (Fig. 17). It provides a durable surface for coverage of amputation stumps (Fig. 18).

Advantages

Distally based radial forearm flaps designed on the proximal forearm can reach the dorsal and palmar surfaces of the hand easily. They can include vascularized tendon and bone. Pedicle lengths of 15 cm are possible. If the flap is less than 6 cm in width, the donor site can be closed primarily. The flap arc of rotation can be increased by freeing the radial artery in the snuffbox and passing the flap underneath the thumb extensors; this allows the flap to reach as far as the thumb tip [38]. The forearm flap permits postoperative elevation and early mobilization of the injured limb. Proximally based flaps can be used to resurface defects well above the elbow joint [52]. These flaps are directly innervated by including the medial or lateral cutaneous nerve of the forearm.

Limitations

Underdevelopment of the radial artery or injury to the superficial and deep palmar arches would preclude the use of this flap, as would the absence of a connection between the radial and ulnar arteries. In Coleman and Anson’s [53] dissection of 650 cadaver arms, only 3.2% had no communication between the radial and ulnar artery, and 3% had an incomplete deep arch. If both of these variations are present, the thumb is dependent on the radial artery (approximately 1 in 1100). This situation can be identified by a preoperative Allen’s test [54]. Vein graft reconstruction of the radial artery would be necessary in these cases. Care should be exercised in acute trauma when hematoma extends to the snuffbox.

Surgical technique

The course of the radial artery is marked [25]. Using a pattern from the recipient site, the size of the defect is outlined on the proximal forearm. If the flap is outlined over the proximal ulnar forearm, it is thinner and less hair bearing. A thin skin island can be left over the course of the radial artery to prevent the need for skin grafting the pedicle later on and to avoid an overlying skin bridge. The flap is incised down to the deep fascia. Veins are harvested along the proximal medial border of the flap; this allows an easier anastomosis with local veins when the flap has been rotated 180°. The medial or lateral antebrachial cutaneous nerve is identified, then a proximal extensile incision is made for a longer nerve pedicle. The SBRN should be protected to preserve sensation to the radial aspect of the hand.

A plane is developed deep to the radial artery at the wrist, and the intermuscular septum is found between the flexor carpi radialis and the brachioradialis. The deep fascia is incised over the flexor carpi radialis muscle belly, well medial to the intermuscular septum. The interval between the deep fascia and the muscle is dissected. The deep fascia is sutured to the skin flap to minimize shear on the septocutaneous perforators. The dissection is continued deep to the radial artery on both sides of the septum. The fascia superficial to the radial artery is left undisturbed because it contains the septocutaneous perforators that supply the skin flap. After the flap dissection is complete, a microvascular clamp is applied to the proximal radial artery before releasing the tourniquet. If there is adequate perfusion to the flap and the thumb, the artery is divided. The flap is raised, ligating all the perforators deep to the artery. The flap is transposed to the dorsum of the hand. If desired, a venous anastomosis is performed before insetting the flap (see Fig. 16D).

Variations

The radial forearm flap can be raised as a composite skin flap including vascularized bone and tendon for thumb reconstruction [55]. A purely fascial radial forearm flap can be used to
Fig. 16. (A) Saw injury with skin and bone loss of distal thumb. (B) Bone reconstruction using iliac crest graft and minicondylar plate. (C) Pedicle reversed flow radial forearm flap. Note skin bridge (SB) over the pedicle. (D) Supplemental venous anastomosis. (E) Insetting of flap. (F) Long-term result.
cover exposed tendons on the dorsum of the hand, but it has to be skin grafted, and innervation is not possible [56]. A reverse radial fascial-fat flap preserves the radial artery and has been used to cover a scarred median nerve [57,58].

**Vascularized bone dissection**

The vascularized bone graft does not carry an intact blood endosteal supply, but instead survives on the periosteal branches. The lateral half of the radius from the insertion of the pronator teres to the metaphyseal flare of the distal radius can be harvested; 10 cm of slightly curved, mostly cortical bone, constituting half the circumference of a circle, is obtained. The perforators deep to the radial artery along the length of the desired bone graft are preserved. Dissection is carried out medial to the intermuscular fascia over the radius. The pronator teres, sublimis muscle, and flexor pollicis longus muscle are divided directly on top of the midline of

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*Fig. 16 (continued)*

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*Fig. 17. (A) Rollover crush injury with devitalized skin, extensor tendon loss, and multiple open fractures. (B) Pedicled retrograde flap based on the radial artery (RA). Note the vascularized palmaris longus tendon (PL) and the lateral antebrachial cutaneous nerve (LABCN). (C) Long-term result.*
the bone; this preserves the musculoperiosteal branches to the bone graft. The osteotomy site is predrilled before performing the osteotomy. The proximal and distal corners are beveled to decrease stress risers and to diminish the risk of postoperative fracture.

**Fascial flap dissection**

A purely fascial flap is raised in a similar manner to the fasciocutaneous flap. The plane of dissection proceeds between the deep fascia and the skin, which divides all the cutaneous branches.

The reverse radial fascial-fat flap survives on retrograde blood flow through perforating vessels coming off the radial artery. These perforators are found within 1.5 to 7 cm from the radial styloid and run directly upward from the radial artery into the fascia (Fig. 19). The fascia serves as a viable supporting membrane for perfusion of the fat on its surface [57]. The most proximal perforators are sacrificed for retrograde orientation of this flap. The fat and deep fascia are developed as a long, distally based rectangular flap. The interval between the fat and fascia is not violated. The lateral antebrachial cutaneous nerve and SBRN are preserved. After elevation, the flap is turned distally 180° and simultaneously twisted 90° to place the vascularized fat layer directly over the median nerve (Fig. 20). The donor site is closed primarily.

**Fig. 18.** (A) Transmetacarpal amputation with unstable stump. (B) Reversed pedicled forearm flap with venous anastomosis. (C) Sensibility testing with Semmes-Weinstein filaments is comparable to other side.
**Sensory recovery**

In one series, the moving 2-point discrimination averaged 13.2 mm. This was more sensitive than the donor forearm, and it was postulated that the sensory return depended more on the recipient nerve than the donor nerve [59].

**Complications**

Postoperative complications include flap edema, unstable skin graft over tendons, hand swelling, and superficial radial nerve injury. Flap edema is common because of associated forearm injury or impaired venous drainage. Additional venous anastomoses help minimize this edema. Skin graft failure is most likely to occur over tendons, especially the flexor carpi radialis. Even when they have successfully taken on tendons, skin grafts may experience recurrent breakdown. Avoidance of the distal forearm as a donor site and covering the tendons with adjacent muscle fibers from portions of the brachioradialis, flexor digitorum superficialis, and flexor carpi ulnaris provide a better skin graft bed. Unmeshed skin grafts can be used to maximize the bridging phenomenon. Preoperative tissue expansion also can be used [60].

The donor site defect is quite noticeable. The flap is hair bearing and often bulky. A radial shaft fracture can occur after harvest of vascularized one; above-elbow casting or splinting for up to 8 weeks is recommended. Although digital temperature comparisons show an average 2.5% decrease after the use of the radial forearm flap, cold intolerance is often transient [61].
Innervated groin flap

The groin flap, introduced by McGregor and Jackson [62] in 1972, was one of the first axial pattern flaps. It was revolutionary because it allowed greater potential for reconstruction of difficult upper extremity wounds. Despite the wide variety of pedicle flaps, the groin flap still has a place in cases in which there are inadequate vessels for a free flap or in which there has been an injury to the carpal arch that precludes the use of a pedicled forearm flap. Joshi [63] modified the flap to include branches of the lateral cutaneous branch of the subcostal nerve (12th thoracic nerve). This modification facilitates sensory innervation of the flap after neurorrhaphy to local donor nerves.

Anatomy

The groin flap is supplied by either the superficial circumflex iliac artery (SCIA) or the superficial epigastric artery (SEA). Taylor and Daniel [64] found the SCIA to be present and greater than 1 mm in diameter 98% of the time. The SCIA and SEA usually arise separately off the femoral artery, although a common arterial trunk was found in 29% of specimens in one series [65]. Either the common trunk or the SCIA is used as the pedicle, unless the SEA is larger.

The SCIA arises from the anterolateral aspect of the femoral artery, 2 to 3 cm below the inguinal ligament. It runs laterally in a line parallel to the inguinal ligament superficial to the iliacus fascia, enveloped by the fatty lymphatic tissue in the femoral triangle. At the medial border of the sartorius muscle, it usually divides into a superficial and deep branch. The superficial branch continues laterally, above the sartorius fascia to supply the skin surrounding the anterior superior iliac spine (ASIS). The deep branch runs underneath the sartorius fascia. It pierces the fascia at the lateral border of the sartorius, 1 to 4 cm below the ASIS, giving off cutaneous and muscular branches. If a long groin flap is required, the deep branch must be included in the pedicle. The vascular network lateral to the ASIS is quite extensive, allowing elevation of a large random pattern skin extension of the flap.

The SEA arises in a similar fashion to the SCIA, then runs laterally, superficial and superior to the inguinal ligament. It remains medial to the ASIS to supply an area of skin above the territory of the SCIA. The territories of these vessels overlap.

The venous drainage is quite variable. The groin area is drained by the superficial epigastric vein, the superficial circumflex iliac vein, and the associated venae comitantes. These veins drain into either the saphenous bulb or the femoral vein. The superficial epigastric vein and superficial circumflex iliac vein lie superficial to their respective arteries and to Scarpa’s fascia. They frequently form a common trunk measuring greater than 2 mm [66].

The sensory supply of the lateral half of the groin flap corresponds to nearly the entire distribution of the lateral cutaneous branch of the subcostal nerve. This branch exits between the internal and external oblique muscles. It descends over the iliac crest about 5 cm behind the ASIS, before supplying the skin over the front part of the buttocks. This nerve branch is separate from the lateral cutaneous nerve of the thigh, which arises from the lumbar plexus (L2 and L3), then travels behind the inguinal ligament.

Indications

The groin flap is indicated for cases requiring massive soft tissue coverage of the hand. It provides a means for the resurfacing of large soft tissue defects—15 × 30 cm. This flap may be used for thumb reconstruction or for limb salvage after a failed free or pedicled flap. It may be useful in selected pediatric cases in which the donor site defect from other pedicled or free flaps may be substantial.

Advantages

The flap anatomy is reliable, and microvascular technique is not a prerequisite to raising the flap. This flap can be used in situations in which inadequate vessels or patient factors (age,
systemic illness, atherosclerotic vessels) preclude the use of a free flap. It may be useful when there is an injury to the superficial and deep palmar arch that precludes the use of a reversed pedicled radial forearm flap (Fig. 21). The donor site scar can be closed primarily and is hidden by a bathing suit. Because regional nerves are used, there is no problem with cortical reorientation.

Fig. 21. (A) Degloving hand injury. (B) Elevation of groin flap. (C) Resurfacing of palm.
Limitations

A history of lymphadenitis or previous surgery in the groin, including hernia repairs, lymph node biopsies, or vein stripping, may preclude use of this flap for fear of prior injury to the vascular pedicle. Patients with marked limb edema, patients with shoulder or elbow contractures, and patients who cannot tolerate prolonged upper extremity immobilization for psychological reasons may not be appropriate candidates.

Surgical technique

The patient is positioned supine with a sand bag under the ipsilateral buttock. The amount of skin that can be removed while still allowing direct closure can be estimated by flexing the hip and approximating the skin edges manually. The pubic tubercle, inguinal ligament, and ASIS are drawn along with a pattern taken from the tissue defect. The most dependable approach is to approximate the flap axis through the center of both vascular territories by drawing a line 2 cm distal to the inguinal ligament that extends past the ASIS.

The flap is elevated from lateral to medial to allow identification of the SCIA or SEA. The flap is based on the larger of the two arteries at the time of dissection. A thin layer of subcutaneous fat is harvested with the skin lateral to the ASIS because this represents a random pattern flap extension of the flap. When the ASIS is encountered, however, the entire width of the subcutaneous fat must be harvested to include the arterial pedicle. The interval between the tensor fascia lata and the sartorius is delineated. The deep branch of SCIA courses from a deep to a superficial plane as it passes through the sartorius fascia to reach the subcutaneous tissue. The fascia and the subcutaneous tissue are elevated carefully from the lateral border of the muscle to prevent injury to the SCIA. If the SCIA is not visible, transilluminating the flap may be helpful.

The subcostal nerve emerges from the oblique muscles and spreads into two branches just below the iliac crest. The nerve is divided at the iliac crest region so that it remains ensheathed in the layers of the groin flap. The two branches are available for suture to donor nerves in the hand, with the pedicle entering on one end and the nerve exiting the other end of the flap [63]. The hand is placed in the groin, and the flap is sewn over the soft tissue defect. Shoulder range-of-motion exercises are emphasized until the flap is divided at 3 to 4 weeks.

Variations

If the flap is tubed for thumb reconstruction (Fig. 22), one side of the flap is cut longer than the other and diagonal closure of the donor site and the flap is performed. This diagonal closure increases the circumference of the tube at the base of the flap, reducing the risk of vascular compression. Diagonal closure also produces a spiral in the tube. The direction of the spiral can be controlled to facilitate closure of defects on the palm or dorsum of the hand [67]. The use of a pedicled, osteocutaneous groin flap to reconstruct a composite interpositional bone loss of the thumb has been described (Fig. 23) [68]. Taylor et al [69] showed the superiority of the deep circumflex iliac vessels when harvesting vascularized bone with the groin flap.

Sensory recovery

In Joshi’s series [63] of four patients, the innervated groin flap provided protective sensation or better. The maximum return of sensation occurred by 4 months compared with 18 months for a noninnervated flap.

Complications

The flap carries pubic hair on its medial aspect. The flap is bulky, and a secondary procedure for defatting may be necessary. Shoulder stiffness is common, especially in elderly patients. Partial fat necrosis, seroma, infection, and complications related to bed rest can complicate the results.
Summary

Any particular soft tissue defect of the hand can be managed in a variety of ways. Often the simplest procedure with the fewest potential complications suffices. Soft tissue coverage is merely one component in the management of complex hand injuries, which also may require bony stabilization, neurovascular repair, and tendon reconstruction. Although not specifically addressed, the role of aggressive hand therapy with edema control, early active motion, and functional retraining cannot be overemphasized. Providing stable soft tissue coverage with the potential for sensibility expands the subsequent reconstructive options and enhances the ultimate functional result. Through an intimate understanding of the neurovascular anatomy, innovative hand surgeons undoubtedly will continue to find new applications for established techniques, limited only by their imagination.

References

NEUROSENSORY PEDICLED FLAPS


