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REVIEW ARTICLE

The Evolution of the Pedicled Radial Forearm Flap

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Abstract Because of the thin skin envelope of the hand, especially at the dorsum, flaps are frequently required for defect reconstruction in the hand. The pedicled radial forearm flap is a time proven procedure that offers reliable coverage in this area without the need of advanced microsurgical expertise. Despite several alternatives and an increasing acceptance of free tissue transfers, the pedicled radial forearm flap can still be the procedure of choice under special circumstances. Variations of the original technique address the two main disadvantages, the conspicuous donor site and the sacrifice of the radial artery. Indications, anatomy, surgical technique, and limitations of this classic workhorse flap are presented.

Keywords Pedicled · Flap · Forearm · Radial · Hand · Fascial · Perforator · Coverage · Review

Introduction

The hand continues to be one of the most difficult areas for reconstruction of soft tissue defects because deeper functional structures such as tendons and vessels are easily exposed even by minor injuries due to the thin skin envelope. Simple skin grafting is rarely an option, and coverage with flaps is frequently required for defect reconstruction. For these situations, the reconstructive ladder suggests to employ the best suited surgical treatment by which reliable coverage can be achieved. However, growing acceptance and refinements in microvascular techniques have led to a tendency to jump the rungs of the ladder in favor of free tissue transfer. As a consequence, free flaps increasingly become the method of choice for the coverage of larger defects in this area despite the increasing complexity of the procedure. Reliable results are achieved, especially with the development of thin fasciocutaneous as well as fascial free flaps. Latter have proven to lead to superior functional and esthetic results, in particular on the dorsum of the hand where thin and supple flaps are required [9, 13].

However, even today, pedicled flaps may be an option worthwhile considering under special circumstances such as extensive preexisting vascular pathology, elderly patients, and situations when the esthetics of the donor site can be neglected. Although a multitude of flaps based on the major arteries of the forearm and their branches has been described for defect coverage of the hand, the classic pedicled radial forearm flap and its variations continue to be the most versatile and most frequently used regional flaps in this area.

Historical Perspective and Indications

The radial forearm flap was developed in China in the early 1970s and originally published by Yang as a free flap [29]. Only later, the pedicled flap based on the

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retrograde flow from the palmar arch was described by Biemer and Lu [19, 24]. Today, it is mainly used as free flap especially when thin and pliable soft tissue coverage, predominantly, in the head and neck area is required. On the other hand, it has proven to be very useful as a pedicled flap, particularly in emergency situations. The dissection is straightforward and reliable coverage can be obtained in a one-stage procedure without the need of repositioning the patient and without advanced microsurgical expertise. Due to its long pedicle, even large distal defects reaching to the level of the fingers can be covered. The simultaneous use of the pedicle to revascularize the thumb has also been described [17]. In selected cases, the radial forearm flap can be utilized to elegantly release contractures of the first web space.

Traditionally, two major drawbacks are associated with the radial forearm flap. First, one of the two principal arteries of the forearm and hand is inevitably sacrificed, potentially compromising the vascular supply of the hand and, more importantly, jeopardizing the possibility of additional microvascular procedures. To overcome this disadvantage, the flap can also be harvested as a perforator flap in order to preserve the main radial artery. Acute ischemia after classic flap harvest, however, is a rare event when sufficient perfusion of the hand can be demonstrated with the Allen test preoperatively. Only one case of acute ischemia after harvest of the radial artery has been published [16]. Although frequently performed in the past [5], it appears today that reconstruction of the radial artery is not indicated to avoid chronic malperfusion of the hand [20]. Meland reported on 13 consecutive patients without vein grafting of the radial artery that showed a delay in rewarming of the hand after 1 min, but no further difference after 5 min [21].

The second point of criticism is the esthetic appearance of the donor site that may be very conspicuous, especially when skin grafting is necessary after harvesting larger flaps. To improve the esthetic appearance of the donor site in the fasciocutaneous flap, many suggestions have been published. Mühlbauer and Soutar recommended restricting flap harvesting to the palmar forearm [22, 23]. Hallock reported about skin expansion in ten patients which allowed conversion of the donor site into a linear scar in five patients [14]. Fenton suggested the coverage of the flexor carpi radialis tendon with muscle fibers to enhance take of a skin graft [8]. Other propositions include the use of full thickness skin grafts, a V-Y flap based on the ulnar artery and the use of artificial dermis [2, 10, 18]. Harvest of the flap as a fascial flap results in a more appealing donor site but makes additional skin grafting necessary in the recipient site [15]. Nevertheless, the appearance of the donor site remains to be a severe clinical drawback of the radial forearm flap.

Anatomy

The radial artery runs in the lateral intermuscular septum that separates the flexor and extensor muscle compartments in the forearm. In this septum, about 1-3 cm proximal to the radial styloid a series of perforators branch off the artery and supply the overlying skin of approximately ¾ of the forearm skin surface via the subdermal fascia. Only an about 3 cm-wide strip on the ulnar dorsal aspect of the forearm is not perfused by these perforators, thereby, allowing an extensive harvest of the forearm skin. Venous drainage is achieved either by cephalic, superficial, or concomitant veins. Latter may not be sufficient in larger free flaps; however, distal venous anastomoses are rarely necessary for pedicled flaps. Multiple anastomoses between the forearm veins permit venous drainage despite intact valves, avoiding the need for valvulotomies [15].

Technique

Preoperative Planning

An Allen test is mandatory to secure perfusion of the palmar arch by the ulnar artery alone. If the Allen is test pathologic, a different coverage strategy must be considered. Doppler examinations to locate the radial artery have proven useful; however, a preoperative angiogram is usually not necessary.

The operation can be performed in axillary plexus anesthesia. With the patient in supine position and the arm on an arm table, the course of the radial artery is marked on the forearm and a template of the defect is created. The template is then centered over the course of the artery. A slight ulnar position might be useful to avoid an even more conspicuous donor site extending to the dorsal surface of the forearm. Care should be taken to achieve a correct position and orientation of the template on the forearm. The radial styloid marks the pivot point of the flap and the distal parts of the defect will be covered by the proximal portion of the flap on the forearm, thus, more distal defects require a more proximal skin paddle. A distal skin extension preserving a cuff of subcutaneous fat around the vessels has proven to be useful to protect the pedicle of the flap and facilitate suturing into the defect without tension. In general, a more proximal position of the flap is desirable, as the donor site is also shifted proximally away from the tendons towards the muscle bellies of the underlying flexor units, thereby facilitating skin grafting of the donor site.

Dissection

Fasciocutaneous Flap (Figs. 1–3)

After closure of the tourniquet, the skin is incised and the radial artery is visualized distally. Dissection begins over the distal/ulnar apex of the flap moving radially in the subfascial plane. Suprafascial dissection is possible, but only recommended for experienced surgeons. In this case, a narrow strip of fascia should be preserved around the pedicle. As in other fasciocutaneous flaps, the fascia may be sutured to the overlying skin to reduce shear forces on the flap. While raising the flap, it is critical to preserve the paratenon of the flexor carpi radialis (FCR) tendon, as this area is at a high risk for loss of the donor site skin graft. However, even if an additional effort is made to preserve the paratenon, exposure of the FCR tendon after poor take of a skin graft is a common complication [8, 25, 26].

The intermuscular septum is then encountered radially to the tendon and dissection is continued between the muscle and the septum towards the radius. Small perforators supplying the periosteum of the bone are coagulated. Care should be taken to preserve the septocutaneous perforators to the skin paddle. After the septum is reached, the dissection proceeds from radial to ulnar, beginning subfascially over the brachioradialis muscle until the septum is reached from the radial side. With the muscle retracted radially, the radial artery and the concomittant veins are exposed within the septum. The superficial branch of the radial nerve is found laterally to the septum and should be separated. The septum with its contents is then traced in a proximal to distal direction, becoming increasingly fragile in the proximal forearm. Once the proximal tip of the flap is reached, the artery is separated from the surrounding tissue.

Figure 1 Traumatic soft tissue defect in a 44-year-old patient with loss of extensor tendons.

Figure 2 Intraoperative result after one-staged tendon reconstruction and coverage with a pedicled fasciocutaneous radial forearm flap. The donor site was skin grafted.

To ensure sufficient perfusion of the flap and the hand, the vessel is proximally clamped after release of the tourniquet. The pedicle is then divided preserving a long subcutaneous vein, which can be anastomosed distally if congestion is

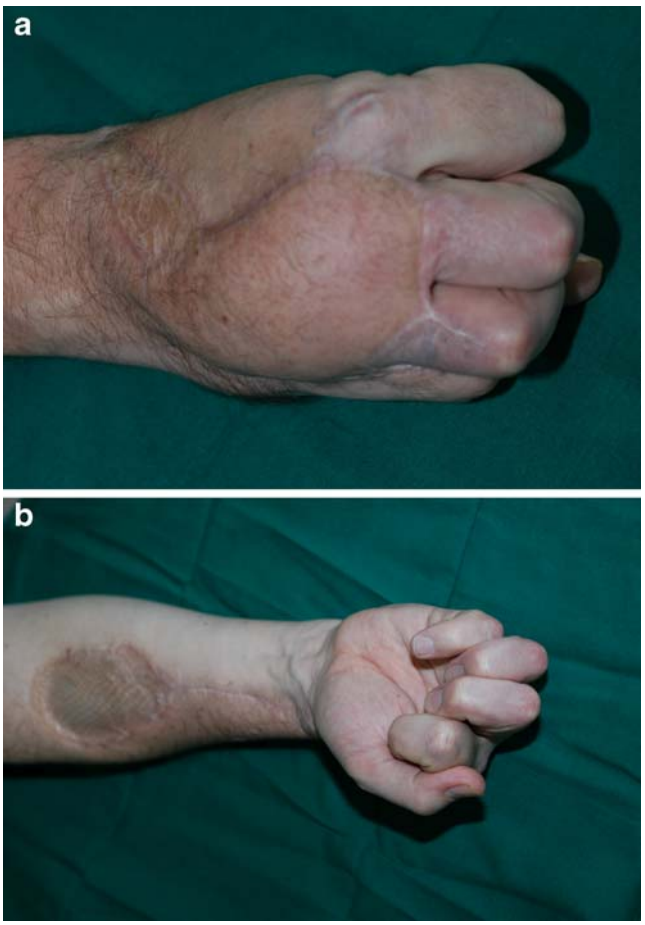

Figure 3 **a** and **b** Postoperative result after 12 months.

encountered (turbocharging)—fortunately, this is rarely necessary. The flap is rotated and sutured into the defect either through a subcutaneous tunnel or an open connection between the donor site and the defect. It is of utmost importance to avoid kinking, tension, and compression of the pedicle. We usually prefer to open the skin bridge between the pivot point and the defect because the course of the vascular pedicle can be controlled more effectively to avoid compression. The donor site can be closed primarily up to a width of approximately 3-4 cm, otherwise a full thickness, split thickness graft, or meshed skin graft is necessary. Immobilization by a cast is not indicated and may increase the risk of compression of the pedicle.

Fascial Flap (Figs. 4–7)

From a curvilinear incision along the axis of the radial artery, a retrograde fascial forearm flap as large as the maximum dimensions of the fasciocutaneous flap can be harvested. In general, the donor site can be closed primarily without the use of a skin graft. For harvesting the fascial flap, the same preoperative routine and template design is applied as for the fasciocutaneous flap. The skin is then incised distally and the radial artery is visualized. After continuing the incision in a proximal direction, the fascia is exposed by elevating a thin cutaneous flap. The fascia is then excised along its radial and ulnar borders and separated from the underlying forearm muscles until the lateral intermuscular septum is encountered in a similar way as in the fasciocutaneous flap. Preserving the septal perforators, the artery is then followed in a distal to proximal direction and subsequently freed from its surroundings. Sufficient perfusion of the hand and the flap by retrograde blood flow is confirmed by clamping the artery proximally and releasing the tourniquet. The flap is rotated into the defect taking care not to compromise the vascular pedicle. Again, we prefer to open the skin bridge between the defect and the pivot point instead of creating a subcutaneous tunnel. The flap is then sutured into the defect and grafted with a sheet split thickness graft rather than a meshed graft because of the superior esthetic result.

Figure 5 Intraoperative result after coverage with a fascial radial forearm flap and split thickness skin grafting.

Discussion

It is generally agreed that early stable soft tissue coverage should be attempted to allow early mobilization and to reduce treatment length and cost [12]. If local flaps are not feasible, free tissue transfer often is the treatment of choice because of superior functional and esthetic results. For coverage of defects of the hand, especially the lateral arm flap, the parascapular flap, the anterior lateral thigh flap as well as temporalis and serratus fascial flaps are excellent options [1, 6, 11, 13]. In our practice, the use of the pedicled radial forearm flap is therefore generally limited to

Figure 4 Soft tissue defect in a 43-year-old patient exposing a reconstructed extensor tendon in the partially amputated ring finger after loss of the second and fifth digit.

Figure 6 Donor site after harvest of the fascial radial forearm flap on second postoperative day.

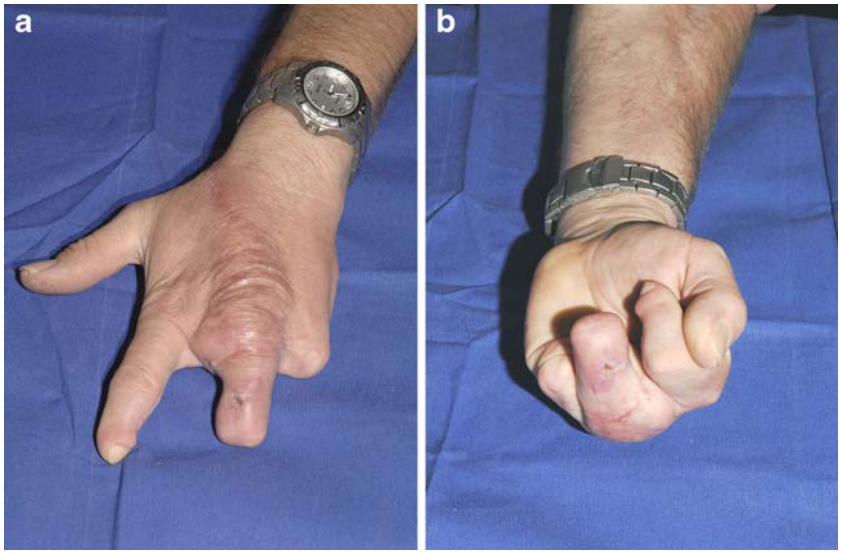

Figure 7 **a** and **b** Postoperative result after 18 months.

patients who do not qualify for free tissue transfer for various reasons. Among these are mainly preexisting vascular pathologies, coagulopathies, or other medical conditions such as malignancies that further limit treatment options or make shorter treatment courses favorable. For these patients, the radial forearm flap offers a time-honored procedure to achieve reliable coverage of large defects of the hand without the need of advanced microsurgical expertise. This benefit has to be weighed against the two major disadvantages, namely the conspicuous donor site and the harvest of the radial artery. These drawbacks remain severe and the indication for the pedicled radial flap should always be made on an individual basis. Although positioning of the flap is theoretically limited due to the attached vascular pedicle, this has not been a problem in our practice. Postoperative range of motion is rather dependent on the cause and extent of the primary defect rather than the type of reconstruction. The ideal candidate for this flap is therefore the elderly, generally compromised patient in need of a one-stage reconstructive procedure who does not qualify for free tissue transfers.

All efforts should be made to improve donor site appearance. We therefore prefer to harvest the flap as a fascial flap as described by Jin [15], especially in staged coverage. This variation offers a superior esthetic outcome of the donor site as well as the recipient site [9]. Nevertheless, the distally pedicled radial arm flap should not be performed in young women (Fig. 6).

Sacrifice of the radial artery, however, remains to be a major issue, that has to be taken into account although variations of the distally pedicled radial forearm flap have been described that rely on perforators in the area of the radial styloid and spare the main vessel [28]. In concordance with the literature, postoperative malperfusion of the hand has not been a serious issue in our patients with a normal preoperative Allen test. More importantly however, the loss of the radial artery limits the possibility of additional microsurgical procedures. For this reason, we further limit the use of the radial forearm flap to defects which can be reconstructed in a one-stage procedure and which do not require further microsurgical tissue transfer.

More recently, we have achieved some favorable results harvesting the flap as a fascial perforator flap while preserving radial arterial flow. However, it has to be taken into consideration that the flap dimensions that can be reliably transferred are smaller due to the retrograde flow that is now more dependent on the fascial plexus rather than an axial vessel. This is can be a problem especially in patients with preexisting vascular disease for which the classic pedicled flap may be indicated. As the perforating vessel usually can be located about 3 cm proximal to the radial styloid, the arc of rotation is further limited. Nevertheless, the radial artery perforator flap provides an excellent alternative to the original flap design that should be taken into consideration especially in smaller defects of the palm.

Several alternative pedicled flaps of the forearm exist that have a similar indication as the radial forearm flap. Among these, mainly the flaps based on the posterior interosseous artery and the dorsal ulnar artery are commonly used.

Zancolli introduced the posterior interosseous island flap in 1985 [30]. In contrast to the radial forearm flap, both major arteries of the forearm can be preserved and a close match of skin color and texture for defects on the dorsum of the hand can be achieved. The donor site can be closed primarily if the flap is harvested less than 5-cm wide, but can be very conspicuous if skin grafting is

necessary. The flap has been subject to substantial criticism mainly due to its delicate anatomy and need for meticulous dissection due to small size of its nourishing vessel and the vicinity to the concurrent motor branch of the posterior interosseous nerve—complication rates as high as 23% have been reported [27]. As reliability is one of the major arguments in favor of pedicled tissue coverage, we consider the posterior interosseous flap only as a second choice although it has been proven very successful in other hands [7, 31].

Another alternative fasciocutaneous flap is based on a consistent dorsal branch of the ulnar artery as described by Becker and Gilbert [3, 4]. As with the posterior interosseous flap, both major arteries are spared and pliable and potentially sensate soft tissue coverage can be obtained. The main disadvantage is the considerably shorter vascular pedicle and the limited arc of rotation, which only allows coverage of the proximal palm and ulnar dorsal, but not the radial border of the hand.

Summary

Despite a number of attractive variations and alternative flaps, we consider the radial forearm flap as the gold standard of pedicled tissue transfer in the forearm against which other pedicled reconstructive options have to stand up to. However, today, free tissue transfer should be preferred if feasible.

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