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GENERAL REVIEW • UPPERLIMB - MICROSURGERY

Lateral arm flap: indications and techniques

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Abstract
The lateral arm flap (LAF) is a popular flap transfer, which can be applied in many procedures. It was first described in 1982, and till then, even more clinical applications are suggested. It can be used as a free fasciocutaneous or fascial flap to cover small- to medium-sized soft tissue defects in head and neck but also in upper and lower extremity reconstruction, or as an osteocutaneous flap when vascularized bone graft is needed. We present the indications and contraindications, the advantages and disadvantages, as well as the step-by-step technique of harvesting a fasciocutaneous and an osteocutaneous flap and its complications. We conclude that the LAF is a reliable and versatile tool for reconstructive surgery, due to its anatomical characteristics and the low complication rate.

Keywords Lateral arm flap · Reconstructive surgery · Microsurgery · Defects

Introduction

The lateral arm flap (LAF) has been established as a popular flap transfer, which can be applied in many different reconstructive procedures such as resurfacing defects in the head and neck area, as well as defects of the extremities. The lateral arm flap was first described by Song et al. [1] as a free septocutaneous flap that can be customized to cover soft tissue or composite hand defects in different topographical areas [2]. Later, the reverse lateral flap as a local pedicle flap was described by Culbertson and Mutimer [3], for the coverage of soft tissue defects around the elbow joint and in the treatment of post-burn antecubital contractures [3, 4]. Katsaros et al. [5], in 1984, further defined the anatomy and clinical applications of the flap, such as the use of a lateral arm flap in combination with a vascularised part of humerus. They reported that one patient received an osteocutaneous lateral upper arm flap with a bone segment 9 cm long. The incorporation of a vascularised portion of the triceps tendon was also reported [5]. The latest series reported by the same group included 11 cases in which the humerus graft was used for tibial, mandible, metacarpal, radius and metatarsal defects [6].

The use as a composite tissue transfer is indicated for various conditions, such as hand reconstruction, thumb reconstruction and reconstruction of combined bone and soft tissue defects in the upper and lower extremity [2, 6, 7]. Such defects can result from trauma, pseudoarthrosis, osteomyelitis or tumor resection. Thumb reconstruction was carried out by the use of osteocutaneous neurosensory lateral arm free flaps in a study published by Arnež et al. [8], while finger reconstruction with a lateral arm fascial flap including a 1.5-cm segment of the distal humerus was reported by Chen and El-Gammal [9]. Harpf and colleagues in 1998 described a series of 72 lateral arm flaps, 70 of which were used as fasciocutaneous flaps [10]. The LAF as composite flap is also indicated for head and neck reconstruction [11, 12].

The lateral arm flap has a consistent vascular pedicle, and it can be designed very distally as an extended lateral arm flap. Katsaros et al. [6] and Kuek and Chuan [13] were the first to report the clinical use of the "extended" lateral arm flap (ELAF) in 1991, as an evolution of the LAF and is designed by an extension of the LAF skin paddle over and beyond the lateral epicondyle toward the proximal forearm. This modification allowed for the use of thinner and more pliable skin from the proximal forearm and a longer pedicle length. The ELAF has been also termed as lateral

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arm/proximal forearm flap, lateral forearm flap [14], distally planned LAF, "extreme" LAF or "true" distal LAF [15].

Anatomy of the flap

The lateral arm flap is supplied by septocutaneous perforators of the posterior branch of the radial collateral artery (PRCA) [5, 16–18] and may include bone, muscle, tendon, nerve, fascia and skin. The profunda brachii artery (PBA) arises in the middle between the acromion and lateral humeral epicondyle, and after it passes posteriorly down the spiral groove, it divides into two main branches: the middle collateral artery and the radial collateral artery. The middle collateral artery runs down into the medial head of the triceps, whereas the radial collateral artery continues along with the radial nerve. Before reaching the lateral intermuscular septum (LIS), the radial collateral artery splits into two branches: the anterior branch of the radial collateral artery (ARCA) and the posterior branch of the radial collateral artery (PRCA). The ARCA is not suitable to provide the basis of the flap because of its variation and the proximity of the radial nerve. The main branch of the RCA that supplies the lateral arm flap is the PRCA [5, 16, 17]. The PRCA travels through the lateral intermuscular septum between triceps posteriorly and brachialis and brachioradialis anteriorly. It gives off four or five septocutaneous perforators along the intermuscular septum and ends into the epicondylar and olecranon network. It eventually anastomoses around the lateral epicondyle with the interosseous recurrent artery [16, 19]. The length of the pedicle is 3.9 cm (range 1.5–6.0 cm), on the anterior aspect of the triceps brachii muscle, but it may reach 7–8 cm by following the vessels to the radial groove [16].

Venous drainage is through one or two concomitant veins that accompany the PRCA, emptying into the profunda brachii veins. Additionally, a superficial venous system drains into the deep veins as well as into the cephalic vein, which courses through the anterior region of the LAF area, emptying into the axillary vein.

Two nerves should be considered in the region. The lower lateral brachial cutaneous nerve (LBCN), arising directly from the radial nerve, provides sensory innervation to the skin of the lateral upper arm; and the posterior antebrachial cutaneous nerve (PACN) innervates a more distal skin area, inferior to the lateral epicondyle, that is used for the extended lateral arm flap [12].

The lateral supracondylar ridge of the humerus, a frequently used source of bone for transfer, is vascularised by two groups of arteries [16]. The first group consists of periosteal branches that originate from the PRCA and follow a direct course to the bone anterior and posterior to the lateral intermuscular septum. These vessels do not penetrate the adjacent muscles, but run between the lateral intermuscular septum and the muscles to the underlying bone allowing the lateral supracondylar ridge to be transferred without impairing the muscles. The second group of periosteal arteries arises from muscular branches, which in turn originate from the PRCA; their origins are scattered among the origins of the direct periosteal vessels of the first group. After the muscular branches enter the muscles, small vessels split off and run nearly perpendicular to the surface of the underlying bone at the site of muscle insertion. These two groups of periosteal arteries give off into a rich network, mainly on the dorsal part of the humerus [16].

Designing the flap

The flap is outlined on the distal third of the lateral aspect of the arm. The axis of the skin island of the flap is centered with a line drawn from the deltoid insertion to the lateral epicondyle, which corresponds to the lateral intermuscular septum (Fig. 1). The axis of the pedicle passes along the lateral intermuscular septum, which is traced between the lateral head of the triceps muscle posteriorly and the brachialis and brachioradialis muscles on the anterior side. The flap pattern depends upon the defect which has to be covered. The more distal the flap is made, the thinner the skin. Giving to the size of the defect, the dimensions of the flap can be extended over and beyond the lateral epicondyle as an extended lateral arm flap (ELAF). Flap width commonly should not exceed 6 cm to allow for primary skin closure of the donor defect.

Harvesting technique

The patient is placed in the supine position and the flap can be harvested with the upper limb on an arm table or with the arm lying on the chest and the elbow in flexion. The entire arm, including the shoulder, is prepped to the axilla. A sterile tourniquet may be used for the procedure and must be placed high up in the arm. If the tourniquet interferes with proximal dissection, it must be deflated at the latter part of flap harvest. Alternatively, a narrow (6–10 cm width) Esmark rubber tourniquet can be applied under moderate tension.

The lateral arm flap is outlined with a surgical skin marker along with the proximal incision to expose the pedicle of the flap, which lies over the lateral intermuscular septum. Posterior flap elevation is performed first. The posterior flap is elevated deep to the muscular fascia over the triceps, which is peeled anteriorly until the septum is encountered. This fascia is included in the flap to preserve vascularity [20]. The fascia is sutured with two to three stitches to the skin to avoid a separation of skin and fat layer. As the flap

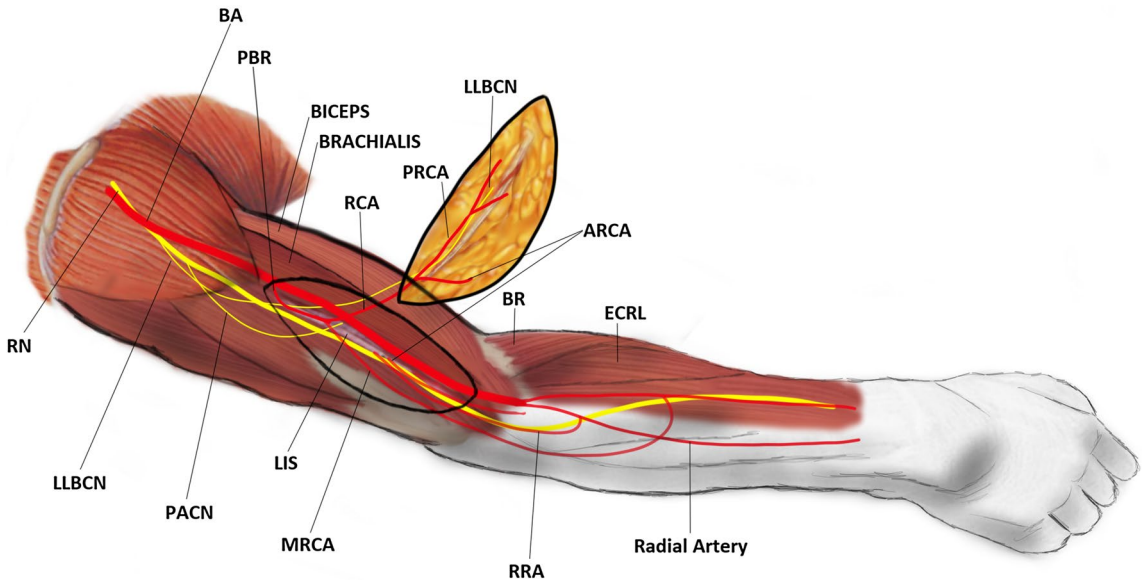

Fig. 1 Raising the flap. *BA* brachial artery, *PBA* profunda brachii artery, *RCA* radial collateral artery, *PRCA* posterior branch of radial collateral artery, *LLBCN* lower lateral brachial cutaneous nerve, *ARCA* anterior branch of radial collateral artery, *BR* brachioradialis, *ECRL* extensor carpi radialis longus, *RN* radial nerve, *PACN* posterior antebrachial cutaneous nerve, *LIS* Lateral intermuscular septum, *MRCA* middle branch of radial collateral artery

is elevated toward the septum, small muscular perforators are encountered and have to be coagulated or ligated. The pedicle and septum are identified together and exposed from distal to proximal.

Then the anterior aspect of the flap is elevated. The same dissection is performed exposing the brachialis and brachioradialis muscles. The fascia here is slightly more attached to the muscles. The flap can be elevated from distal to proximal. The artery and vein at the distal aspect are ligated and divided. Staying deep to these vessels, the intermuscular septum is released to the level of humeral periosteum and the septum is now raised, with periosteum, from the humerus proximally to the level of deltoid insertion. As the dissection proceeds more proximally, the distance between the vessels and the humerus increases, and the dissection is easier. The radial nerve comes into view proximally (Fig. 1).

Once adequate pedicle length is gained, the PRCA and venae comitantes are divided and used as the pedicle of the lateral arm flap. If the neurosensory flap is to be harvested, the lower lateral brachial cutaneous nerve (LLBCN), which enters the skin flap proximally and superficial to the triceps fascia, is identified and divided proximally.

To gain more pedicle length and a wider caliber of vessels, the incision can be elongated by extending it proximally. The triceps and brachialis muscles are retracted to identify the proximal pedicle and to ligate branches. The RCA and its venae comitantes are cautiously separated from the radial nerve, while care should be taken not to retract the nerve. The anterior branch of the radial collateral artery (ARCA) is ligated distally from the bifurcation of the RCA, and further dissection of the RCA is accomplished proximally up to its origin to the profunda brachii artery.

Following hemostasis, the donor site is closed primarily if the flap width is less than 5–6 cm. Otherwise, a split thickness skin graft is used, after reduction in the defect size by closing the proximal and distal ends primarily. In some conditions, a Z-plasty can be used for primary skin closure to avoid a straight scar on the lateral side of the elbow.

Osteocutaneous lateral arm flap

If a vascularised bone graft is required, an osteocutaneous lateral arm flap can be raised. The approach is similar to the standard flap description. It is important to preserve the 3–4 small periosteal branches from the PRCA in the intermuscular septum which supplies the distal lateral humerus. For the harvest of the lateral supracondylar ridge of the humerus, the lateral intermuscular septum should be left attached to the humerus to avoid accidental injury to the septocutaneous branches within [16, 21, 22]. The PRCA has to be centered in the middle of the bone graft, and it is essential to preserve the periosteum attached to the bone. A muscular portion of brachioradialis and extensor carpi radialis longus anteriorly and triceps brachii posteriorly can be included to protect the periosteal branches. A segment of bone between 3 and 6 cm above the lateral epicondyle can be harvested with a

consistent blood supply from the periosteal branches of the PRCA [16, 22].

Indications/contraindications

The lateral arm flap is a versatile transfer for various reconstructive purposes, including composite defects which require bone, tendon or sensory nerve reconstruction. As other free flaps have been described and widely used during the last decades [23–25], it can be used as a free fasciocutaneous flap not only in head and neck but also in upper and lower extremity reconstruction. It can be raised as a fascial flap, including the overlying fat if bulk if required. Commonly, this flap is applied for small to middle-sized hand and wrist defects, as a free fasciocutaneous or fascial flap for dorsal or as free fascial flap for palmar defects. Moreover, it can be used for reconstruction of the nose, the mandible and closure of traumatic metatarsal defects.

The LAF can be used as a local flap to cover defects over the shoulder and elbow. It can be islanded proximally on the posterior radial collateral artery for defects of the upper arm reaching to the coracoid area or the axilla, or distally as a reverse flap, based on the interosseous recurrent artery, for reconstruction of soft tissue defects (Fig. 2) or burn contractures around the elbow region [3, 4].

The use of lateral arm flap may be contraindicated in cases previous trauma or surgical procedures of the donor area, due to the uncertain perforator dependent vascularity of the flap. In addition, the LAF is less suitable for defects wider than 5–6 cm or otherwise skin grafting may be needed, followed by a secondary procedure for scar correction. Furthermore, in case of a patient with serious comorbidities or poor general health status, the use of other less demanding and shorter reconstructive procedures may be indicated. Other relative contraindications are mainly esthetic reasons like hair transfer in cases of face, neck or palmar hand defects, considerable BMI of the patient which results in a bulky flap and the rather obvious scar of the donor site.

Advantages/disadvantages

The lateral arm flap has several advantages over other flaps. It has a consistent anatomy and blood supply for local and free tissue transfer [5, 10, 12]. Its pedicle is a non-dominant end artery, constant and easy to dissect. Additionally, the unique vascular plexus over the lateral elbow region allows great variability in design. The flap is relatively thin, potentially sensate, providing thin skin essential for hand reconstruction [4, 5, 14, 15]. It is a versatile flap and it can be used as a composite flap, e.g., tenocutaneous, osteocutaneous and fasciocutaneous flap which can provide the feasibility to reconstruct three-dimensional defects in a single-stage approach [2, 6, 7]. The donor site can be closed primarily with minimal morbidity. The resultant scar can be easily covered by a T-shirt, in contrast to the radial forearm flap.

The disadvantages of the lateral arm flap include paresthesia or anesthesia of the posterolateral side of the arm and forearm, due to transection of the LBCN and/or the PACN. However, this area of hyposensibility is significantly reduced after 6 months because of ingrowth of the neighboring cutaneous nerves [26, 27]. In obese patients, the bulkiness of the flap may lead to patient dissatisfaction and secondary defattening procedures. Also, hair growth in the skin territory of the flap in some male patients can sometimes be an inconvenience, especially when the flap is transferred to the head and neck region.

Complications

The problems with the LAF/ELAF transfer relate to donor site morbidity. Lateral epicondylar pain and hypersensitive scar, present in 19.4% and 17% of Graham et al.'s series

Fig. 2 52-year-old patient developed an infection of distal humerus after an osteosynthesis with two plates due to distal humerus fracture. A reverse lateral forearm flap distally based on the interosseous recurrent artery was performed. After thorough surgical debridement, the plates were exposed (**a**), and the soft tissue defect was covered with the reverse lateral forearm flap. **b** The donor area was primarily closed (one half), and the other half was covered with split thickness skin graft

Table 1 Summary of lateral arm flap series

	No. of patients	Follow-up	Complications	Conclusion
Graham et al. [27]	123	3 years	27% unsatisfactory appearance (twice as likely in female patients) 19% elbow pain 78% hair formation	Lateral arm flap should be limited to males and cases in which the resulting donor site can be closed primarily
Harpf et al. [10]	72	6 months–10 years	15.3% arterial or venous thrombosis	Outcome without nerve coaptation was more satisfactory than with the nerve coaptation
Akinci et al. [7]	74	3.6 years	7% lost due to venous thrombosis 21% uneven color match and cold intolerance 12% required thinning procedures 9% hair growth	Versatile in covering moderate-sized defects of the upper extremity with little morbidity and with acceptable cosmesis
Ulusal et al. [2]	118	17 ± 6.2 months	Three losses (one arterial occlusion and two deep wound infections) 84.5% required secondary procedure to improve functional outcome 16.1% required debulking procedures	LAF and its variants can be reliably used and provide stable skin coverage with satisfactory cosmetic outcomes in hand defects. However, overall functional outcome is invariably affected by the initial severity of the injury

[27], are associated with patient dissatisfaction. The use of a split thickness skin graft to cover the donor site is likely to result in unsatisfactory appearance. Lateral epicondylar pain is most often associated with primary closure of the donor site. This may relate to tight wound closure or to the inclusion of the epicondylar periosteum into the flap [26]. Some restriction in elbow motion may be also resulted.

Fascia closure and hematoma formation of the donor site have to be avoided as they can lead to elevated intracompartmental pressures and subsequent compartment syndrome. Another serious complication, in case of an osteocutaneous lateral arm flap, is the iatrogenic fracture of the humerus which has to be treated accordingly, in order to avoid malunion, nonunion or ipsilateral elbow stiffness.

Additionally, while lateral forearm numbness is a common postoperative complaint, the formation of a painful neuroma of the PACN may have to be treated in another surgery with neuroma resection and coverage of the stump under healthy soft tissues. A thorough discussion with the patient explaining the details of this procedure in terms of potential donor and recipient site morbidity will set realistic expectations and diminish the risk of dissatisfaction of the patient following this complex surgery [27].

Discussion

In the recent years, due to its advantages over the alternative flaps, it has been widely accepted as a microsurgical workhorse for soft tissue reconstruction of small to medium defects of the extremities and head and neck region when a free flap may be necessary. LAF/ELAF has a constant vascular anatomy (terminal branch of the PBA) which does not compromise the vascular supply of the hand as it does not sacrifice a major artery. Also the dissection is relatively easy and allows two surgical teams to work simultaneously which reduces the total surgical time. Additionally especially for upper extremity reconstructions, it provides good surface for tendon gliding and also a vascularized tendon can be harvested as well as a segment of bone. This allows a single-stage reconstruction of composite defects and early mobilization which is a key factor for optimal results. Moreover, secondary surgical procedures such as debulking and tenolysis can be easily performed. The donor site can be closed directly to a width of up to 8 cm and is in areas that can be concealed with low morbidity and acceptable esthetic results. Despite all the advantages, an important drawback is that this flap has a relative short pedicle length compared to others, such as the radial forearm and the anterolateral thigh flaps [7, 17, 28].

There are several series presenting cases treated with LAF and its variations. Table 1 summarizes the largest series.

Graham et al. [27] in 1992 performed 123 LAF over a 7-year period with 89% of them reviewed over a 3-year period and reported complications and morbidity of the donor and recipient sites, such as 27% unsatisfactory appearance of the donor site which was twice as likely to be reported in female patients and in cases that demanded split thickness skin graft for closure, elbow pain in 19% and hair formation in 78% of patients.

Harpf et al. [10] in 1998 transferred 72 free LAF in 68 patients and studied the effect of nerve coaptation versus no nerve coaptation measuring the objective and subjective grades of sensibility at the recipient site. The follow-up was 6 months to 10 years, and surprisingly, the outcome

without nerve coaptation was more satisfactory than with the nerve coaptation.

Akinci et al. [7] conducted a series of 74 LAF on 72 patients and reported 93.2% success rate with 7% lost due to venous thrombosis. A higher failure rate was encountered with the cases of high-voltage electric burn.

Some of the larger series of LFA is from Ulusal et al. [2] in 2007 described a series of 118 traumatic hand defects treated with the use of LAF from 1990 until 2004. The mean follow-up period was 17 ± 6.2 months, and the overall success rate was 97.5%. Only 16.1% required debulking and poor functional results were described for the recovery of the hand contractures and the reconstruction of the extensor tendons in the composite flap group.

In conclusion, LAF and its variations could offer us a reliable tool for treating defects of different types, due to its anatomical advantages as well as the low complication rate after its use. So we propose the use of LAF for small- or medium-sized defects in the upper extremity as well as head and neck, after a thorough discussion with the patient and the use of this method by a skilled and experienced surgeon with thorough knowledge of the anatomy of the upper extremity.

Compliance with ethical standards

Conflict of interest All authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

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

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