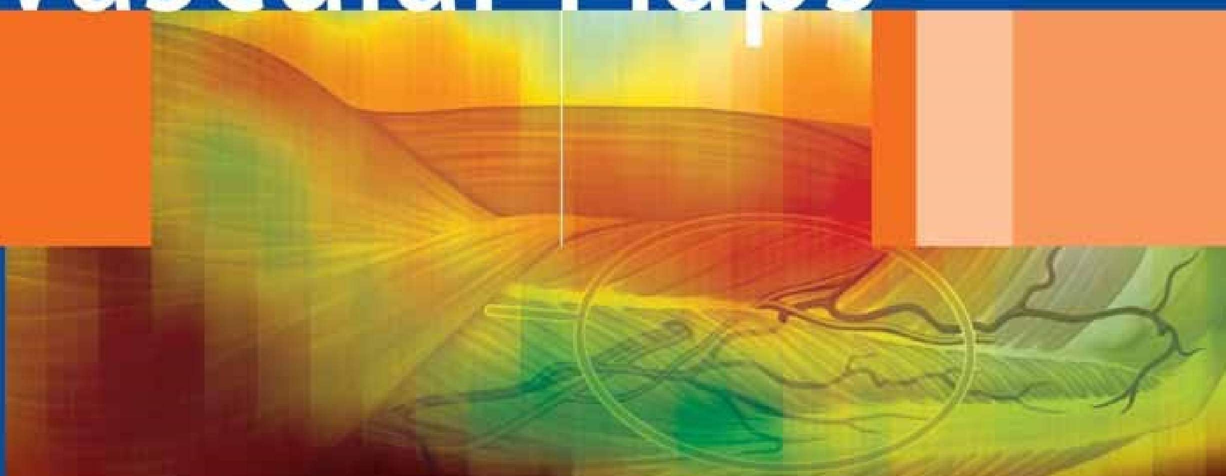
K.- D. Wolff

F. Hölzle

Raising of Microvascular Flaps



A Systematic Approach

DVD-ROM INCLUDED

Springer

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Raising of Microvascular Flaps

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With 106 Figures and 41 Drawings

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This book is dedicated to those

who gave their bodies to the purpose

of teaching and science in medicine

Preface

With the introduction of microvascular tissue transfer in the early 1970s, a new universe of reconstructive possibilities was opened. Meanwhile, this technique has proven to be one of the most important developments for our patients. One of the reasons for this triumphal march of reconstructive microsurgery is the high number of excellent textbooks describing all the numerous flaps that can be raised from nearly every region of the human body. Despite the fact that much high-level literature is already available, we decided to write another book about flap raising. There were two reasons for this decision: during our anatomical courses on flap raising that we have been giving for more than 10 years, we observed that many participants still have difficulties in exactly defining the structures at the donor site, although their anatomical knowledge was generally good. The written descriptions of the anatomy and schematic drawings they used to prepare for flap raising provided less information for the surgeon than high-quality photographs taken from clearly dissected sites. Secondly, important anatomical landmarks and structures were often neglected or destroyed in the early phase of the operation, and the lack of a system in flap raising became obvious. To overcome these problems, the demanding and complex flap-raising procedures were split up into a series of exactly defined sequences of flap elevation. This system was developed during our courses and is now used in this book. It turned out to be extremely helpful not only in improving the understanding of the regional anatomy, but also in increasing the safety and success of flap raising.

The decisive stimulus to our book was provided by the opportunity to use cadavers that had been embalmed according to the method of Thiel. As can be seen from his brilliant photographic atlases, this embalming method provides excellent conditions for carrying out anatomical dissections. Thus, we decided to perform flap-raising procedures on this bloodless tissue. Moreover, the Thiel fixation method provided us with our first opportunity to shoot flap-raising video films without the usual restrictions of a sterile OR and the disadvantages of bleeding and poor visualization of the site.

The operative techniques and order of the individual steps we describe are based on clinical experience and on recognition of the typical failures and difficulties that have occurred during our flap-raising courses. Although various techniques, flap elevations, and approaches have proven useful at the different donor sites, we decided to focus solely on one standard procedure for each flap. These standard procedures represent the best combination of safety, simplicity, and reliability and can be varied or expanded as soon as the surgeon has gained more experience. To meet the demand of readily available, precise, and comprehensive information, instruction on flap raising is mainly given by anatomical photographs and some schematic drawings. The aim of the text is to describe each single step of flap raising and thus to enhance the teaching character of this book. Moreover, an adequate amount of text is added to give an overview of flap anatomy and development. Additionally, the videos that follow the same system and surgical techniques described in the book are intended to help the surgeon prepare for the flap raising.

I hope this book will add further stimulus to learn the techniques of flap raising and will contribute to make microvascular tissue transfer an attractive and comprehensible method for all surgeons who are involved in oncology and reconstructive surgery.

K.-D. Wolff

Acknowledgements

This book would not have been possible without the help and valuable support of some good friends and esteemed colleagues. First of all, I would like to thank the anatomists, who offered us the opportunity to run our flap-raising courses and perform all the dissections on cadavers. In this respect, I am also extremely grateful to Prof. Graf and Prof. Bogusch from Berlin. Moreover, Prof. Dermietzel, who in Bochum provided us with all the support we needed, founded an anatomical research center for clinicians at Ruhr University. The willingness of these anatomists to open the doors of their institutes to clinicians led to interesting events with fruitful discussions and inspired many participants to carry out further anatomical studies to answer specific clinical questions. The permanent and increasing demand for our courses has proven their outstanding importance to maintaining and improving our knowledge of human anatomy. Decisive for the quality of the photographs and videos was the embalming procedure for the cadavers, which was performed professionally by Claudia Schneider and Helmut Riese, who were always friendly and helpful. Harald Konopatzki provided us with excellent schematic drawings for teaching. His insight into anatomy, his experience as an illustrator, and his artistic talent enabled him to realize our ideas and wishes exactly. It was a pleasure to work with him.

I am also very grateful to Andreas Beyna who shot the videos and processed and improved the photographs of the cadaver preparations. His professional knowledge made an important contribution to the quality of the figures and videos. Moreover, I would also like to express my gratitude to Springer-Verlag, especially Ms. Martina Himberger, for all the useful advice and professional and reliable realization of this project and Mrs. Shirley Faatz for reading and improving the manuscript. My most important advisor and supporter undoubtedly was and still is my colleague, Dr. Frank Hölzle. He continually encouraged me to do this work and did not hesitate to push things forward. With his enormous anatomical knowledge, his ability to organize, his enthusiasm for microsurgery, criticism, and useful proposals, he markedly improved the quality of this book.

However, most of my gratitude goes to my family, my dear wife Bruni and our children Carolina and Constantin, who showed virtually endless patience and understanding for my work. With their love, whole-hearted support, and cheerful natures, they were always able to instill me with new energy; thus, they deserve the highest respect for the completion of this book.

K.-D. Wolff

Contents

Chapter 1

Radial Forearm Flap

1

Development and Indications

In 1978, a fasciocutaneous free flap from the volar aspect of the forearm and pedicled on the radial artery was first used in China. When this so-called "Chinese flap" was originally described by Yang et al. in 1981 [293] and Song et al. in 1982 [239], both groups had already performed more than 100 successful flap transfers. Shortly thereafter, this technique was popularized by different European surgeons, who visited their colleagues in China. In 1981, Mühlbauer was the first to describe the advantages of the radial forearm flap in the European literature, especially its excellent pliability, thinness, the ease of flap raising, the consistent anatomy, and the long and high-caliber vascular pedicle [179, 180]. Very soon many authors began to favor this flap for reconstructions in the head and neck region and for intraoral lining. In a number of publications, Soutar and coworkers reported on different indications of the radial forearm flap for reconstructions of the oral cavity and the hand [242, 243, 244, 245], and Cheng used this flap for tongue reconstruction [35]. Hatoko et al. and Chen et al. favored the forearm flap for defect coverage of the hard and soft palate and thus proposed this flap for rehabilitation of the cleft lip and palate patient [37, 101]. In addition to reliable closure of oroantral fistulas, they were able to resurface the alveolar ridge and build a vestibule for reliable fitting of dentures. Moreover, the forearm flap was used as a tubed flap to reestablish phonation ability or deglutition by inserting it in defects of the hypopharynx, trachea, or esophagus [36, 96, 292]. By including a bony segment of the radius, an osteocutaneous flap can be raised, which was proposed for mandible reconstruction [180, 245, 246]. Because of the rich vascularization, two or more isolated skin paddles can be built that are suitable for closure of perforating defects of the oral cavity [24]. Niranjan and Watson described a technique for cheek reconstruction using the tendon of the palmaris longus muscle to elevate the denervated angle of the mouth [186]. Lip reconstructions were performed by incorporating a segment of the brachioradialis muscle into the radial flap, which then was reinnervated by a branch of the facial nerve and sutured to the ends of the resected orbicularis muscle [212, 252]. As another variation, vascularized fascial flaps from the forearm were placed into the oral cavity to allow reepithelialization and thus achieve a mucosal surface [156]. When covering the fascia with a skin graft prior to flap raising, ultrathin flaps can be prefabricated that show less shrinkage than pure fascial flaps. Moreover, the appearance of the donor site is improved by linear closure of the forearm skin, which is not used for flap raising [288]. Although sensory recovery of the radial forearm flap may be facilitated by anastomosing a branch of the antebrachial cutaneous nerve to a sensory nerve of the recipient site [271], according to clinical experience, sensation will at least partially be reestablished spontaneously after some years even without neurocutaneous anastomoses, probably by nerve sprouting.

Apart from these many indications in the head and neck area, the radial forearm flap is a workhorse flap in traumatology of the extremities and trunk and may be used in many other reconstructive procedures.

Anatomy

The radial artery, which forms the deep palmar arch at the hand, is located in the lateral intermuscular septum between the brachioradialis and flexor carpi radialis muscles, giving off 9–17 branches to the forearm fascia [273], most of them existing in the distal third of the forearm. The strongest of these branches, the cubitalis inferior artery, is located proximally in the forearm [229, 273]. These numerous fascial branches form a dense fascial plexus that provides perfusion of the entire forearm skin. Because of this, the forearm flap is a fasciocutaneous flap. Although the radial artery, which terminates in the deep palmar arch, is the main vessel source for the cutaneous branches of the forearm, the ulnar artery and the anterior and posterior interosseous arteries contribute to the blood supply of the forearm skin and hand as well [45]. According to a clinical study by Kerawala, the mean arterial backflow pressure of the distal stump of the radial artery is on average 40 mmHg [127]. Thus, the vascular supply to the hand is normally maintained, and ischemia of the hand after raising the radial flap [122] or vascular anomalies, such as duplication of the radial artery [157, 217] or other irregularities [238], are seldom described. A number of unnamed branches of the radial artery to the skin, muscles, and periosteum enable the transfer of different flap types with a great variety in design and flap components. Bearing in mind the fact that the entire skin of an amputated forearm can be safely transferred at the radial artery alone [273], the size of the flap can vary considerably. Song and Gao pointed out that all cutaneous vessels travel along with the antebrachial fascia, most of them between the brachioradialis and flexor carpi radialis muscles at the distal third of the forearm [239]. Because of this, the forearm fascia must be left attached to the undersurface of the skin during flap raising. Nutrition of the bone is provided by periosteal and direct medullar and indirect vascular branches, which perforate the flexor pollicis longus muscle and anastomose with the medullary vascular system. Alternatively, the forearm skin can be transferred at the ulnar or cubitalis inferior artery, designing the skin paddle over the ulnar side of the forearm. Because the ulnar skin has less hair, the skin quality of the ulnar forearm flap is considered to be higher [142], leading to less donor-site morbidity when raised at the proximal part of the forearm [150]. A disadvantage of the ulnar forearm flap is that it carries significantly fewer cutaneous branches. According to Morisson, cutaneous branches from the ulnar artery can be missing completely [177].

Venous drainage of the forearm flap is established either by the deep radial veins or by the superficial venous system, which forms multiple anastomoses between each other. Because of the different branching patterns of the deep and superficial venous systems and the variability of the size and course of the subcutaneous veins [261], the decision of whether or not to anastomose a superficial or deep vein depends on the individual situation. Although the large caliber of the subcutaneous veins permits an easier anastomosis, venous drainage by the superficial system can become unreliable in small flaps and after occult damage of the intima, for example caused by repeated catheterization of the vein. Flow volumes of the superficial and deep veins have been measured using Doppler ultrasonography, showing a significantly higher blood flow through the deep veins than in superficial veins in the early stage of flap transfer [115, 116]. Despite the presence of valves in the deep and superficial system, retrograde flow is possible via the numerous interconnecting veins, allowing distally based radial forearm flaps to be raised [68, 147, 155, 262], which may be useful as pedicled flaps to cover defects of the hand [121].

Advantages and Disadvantages

The radial forearm flap is a thin, pliable, and mostly hairless fasciocutaneous flap, having great value for reconstructions in the head and neck region, especially in the oral cavity. The high caliber of the vessels (artery 2–3 mm, cephalic vein 3–4 mm, deep veins 1–3 mm) and the long vascular pedicle and variability in flap perfusion (ortho- and retrograde flow, venous drainage via the superficial or deep system) are of considerable help when constructing anastomoses. In the head and neck area, flap raising is possible at the same time as tumor resection and can be carried out quickly. Because of the ease of flap elevation, the radial forearm flap is recommended for beginners in free-flap surgery.

Besides these advantages, however, some of the disadvantages should be pointed out concerning the donor site of the forearm flap: Because harvesting the flap always leads to complete interruption of the radial artery, perfusion of the hand must be maintained by the ulnar artery and the remaining anterior and posterior interosseous vessels. In an anatomic investigation on 750 cadavers, the radial and ulnar arteries were found to be always present, and the dominant vessel for hand perfusion was regularly found to be the ulnar artery, which terminates in the superficial palmar arch [169]. Despite this, blood supply to the thumb and index finger can totally depend on the integrity of the radial artery if two anatomical variations coexist: (1) If there are no branches of the superficial palmar arch to the index finger and thumb and (2) if there is no anastomosis between the deep and superficial palmar arch [4, 48]. To prevent postoperative ischemia of the hand, Allen test or, if still in doubt, an angiography must be carried out to prove the reliability of hand perfusion via the ulnar artery. An absence of the radial artery was described by Porter, who found the arterial supply of the forearm to be based on codominant median and ulnar arteries [191].

A considerable disadvantage is the appearance of the donor site, which is located in an esthetically exposed region. A number of publications can be found reporting on complications at the donor site at a frequency of 30–50 %, mostly caused by the poor transplant bed for the skin graft [14, 23, 67, 70, 90, 91, 92, 160, 171, 243, 244, 249, 263]. To reduce donor-site morbidity, different techniques have been developed to achieve direct wound closure, such as the VY plasty [67], the transposition flap [14], the use of tissue expanders [90, 160], or prelamination of the forearm fascia [288]. According to McGregor, the take of the skin graft can be improved by placing the wrist in an extended position for 20 days [171]. To achieve protection of the flexor carpi radialis tendon, it was proposed that this tendon be covered by oversewing it with the flexor muscles [70] or that a well-vascularized bed for the split-thickness skin graft be provided by approximating the flexor digitorum muscle to the flexor and abductor pollicis longus muscles [133]. In addition to these problems concerning the healing of the donor site, other complications such as edema formation, reduced strength and extension of the hand, loss of sensation because of injury of the superficial branches of the radial nerve, and cold intolerance have been reported [263]. Following harvest of an osteocutaneous forearm flap, the arm has to be immobilized for about 6 weeks, but fractures are nevertheless common [263], unless the donor arm is primarily stabilized by rigid fixation using plates [274]. Using the tibia of sheep, Meland and coworkers have found considerable weakness and loss of stability of the bone even if only small amounts of the cortical bone have been removed [173]. Therefore and because other flaps are available that provide much more bone material to be raised, the osteocutaneous forearm flap cannot be considered a method of first choice for mandible reconstruction. Finally, there is a tendency for edema to form in the flap, probably by changing the perfusion from a "flow-through" to a "terminal flow" pattern. This edema can sometimes cause functional restrictions, especially in the oral cavity, but within a few weeks it will resolve spontaneously [25]. Although the radial forearm flap is still a workhorse flap, especially in the head and neck area, these disadvantages may considerably reduce its acceptance among surgeons and patients [153]. Alternative methods with less donor site morbidity, for example perforator flaps, have been introduced for defect cover in the head and neck region with similar indications as for radial forearm flap [291].

Flap Raising

Preoperative Management

The Allen test must be performed to assess the adequacy of the circulation of the hand (especially the thumb) through the ulnar artery alone after sacrifice of the radial artery. Flap raising is carried out on the nondominant arm (mostly on the left side). The use of a tourniquet is not mandatory, because with ongoing hemostasis, the operating field can be kept absolutely dry even in the perfused arm.

Patient Positioning

The arm is brought into an abduced, supine position so that the volar aspect of the whole forearm can be used for flap elevation. Circular disinfection is necessary from the fingers up to the axilla.

Standard Flap Design

The distal flap border is placed 3 cm proximal to the wrist, and the ulnar margin of the flap is outlined over the flexor carpi ulnaris muscle. If the cephalic vein, which is variable in size and course and can be missing completely, is not used for venous drainage, the radial flap margin is placed over the brachioradialis muscle. The flap should not be extended to the dorsal aspect of the arm for aesthetic reasons. Drainage through the deep veins alone is always reliable and sufficient. The position of the proximal margin depends on the flap size needed. For exposure of the proximal vascular pedicle, a wavy-line incision helps to reduce postoperative scar shrinkage.

Flap Raising

The skin is incised at the ulnar border through the subcutaneous fatty tissue until the forearm fascia is reached. The fascia, which has a dense, tight structure, is bluntly undermined above the flexor carpi ulnaris tendon. Step 1

The fascia is incised and elevated until the tendon of the flexor carpi ulnaris muscle is exposed. The paratenon that envelops the tendon is left untouched. The cut margin of the fascia is clearly visible. Step 2

The incision at the distal margin is made through the skin and fascia in the same fashion. The flap containing skin, subcutaneous tissue, and fascia can now be elevated. The rest of the dissection is performed strictly underneath the fascia, and the tendons of the flexor digitorum and palmaris longus muscles become visible. The fibrous attachments between the undersurface of the forearm fascia and the paratenon are carefully transected. The paratenon itself is not removed. If the palmaris longus tendon is hypoplastic, it is transected and left attached to the fascia. Step 3

Now, the strong tendon of the flexor carpi radialis muscle is reached and subsequently isolated from the forearm fascia in its distal portion. Step 4

Directly radial to this tendon, the radial artery is palpated, which runs into the septum between the flexor carpi radialis and brachioradialis muscle. At the most distal point, this septum is opened and a short segment of the radial artery is exposed. Before ligating the artery, which is Step 5 always accompanied by two veins, the superficial branch of the radial nerve is identified over the tendon of the brachioradialis muscle. The nerve is carefully preserved during further dissection.

Step 6

The radial artery is divided at the distal border of the flap. In the perfused arm, the pulsation of the distal stump of the radial artery, caused by the intact circulation through the palmar vessel arches, is visible.

Step 7

Now, the skin incision is made 1 cm radial to the artery down to the forearm fascia. The cephalic vein and the superficial branches of the radial nerve are left intact. If the cephalic vein is included and used for venous drainage, the flap is extended toward the dorsal aspect of the forearm, and the cephalic vein is divided distally.

Step 8

The fascia is incised, keeping a safe distance from the radial artery, and the tendon of the brachioradialis muscle is exposed and retracted laterally. Having identified the superficial branch of the radial nerve, the intermuscular septum containing the radial artery is separated from the brachioradialis muscle. The artery is carefully elevated together with the flap and remains firmly connected to the forearm fascia. Numerous small branches to the deep muscles and radial bone have to be cauterized or clipped in this area. The deep dissection plane during this step of flap raising is above the flexor pollicis longus muscle.

Step 9

It can be clearly seen that the undersurface of the flap is built by the forearm fascia and that the vascular bundle is securely attached to the fascia by the intermuscular septum. In the distal third of the forearm, where the radial artery is not covered by muscle bellies, the septum contains the highest number of cutaneous perforators. Because these perforators first reach the fascia to form a dense vascular network before they enter the skin, the radial forearm flap is a fasciocutaneous flap. The hypoplastic tendon of the palmaris longus muscle is left attached to the flap fascia and is removed from the forearm for a better take of the skin graft.

Step 10

In addition to the safe skin perfusion in this area, outlining the flap over the distal third of the forearm has the advantage of obtaining a long vascular pedicle. For dissection of the pedicle, the skin incision is made at the proximal border of the flap, where one or more cutaneous veins that run superficial to the fascia can be observed. If a vein is identified coming from the central part of the flap, it can be left intact for additional venous drainage. A wavy skin incision is made to expose the proximal segment of the vascular pedicle.

Step 11

Prior to incision of the forearm fascia, the superficial cutaneous vein is traced proximally by careful subcutaneous dissection. To test drainage adequacy, blood flow through this vein is observed by cutting it proximally at the end of flap raising before the radial artery is ligated. If there is adequate return of venous blood, the vein can be used as additional drainage to the deep radial veins. By careful preparation, a cutaneous antebrachial nerve becomes visible, giving the opportunity to create a sensate flap.

Step 12

The forearm fascia is now incised between the bellies of the brachioradialis and flexor digitorum muscles, and the vascular pedicle is exposed by retracting the brachioradialis muscle. It can clearly be seen that the septum between the brachioradialis and flexor digitorum muscle has been removed from the distal third of the forearm where the skin paddle was raised.

Step 13

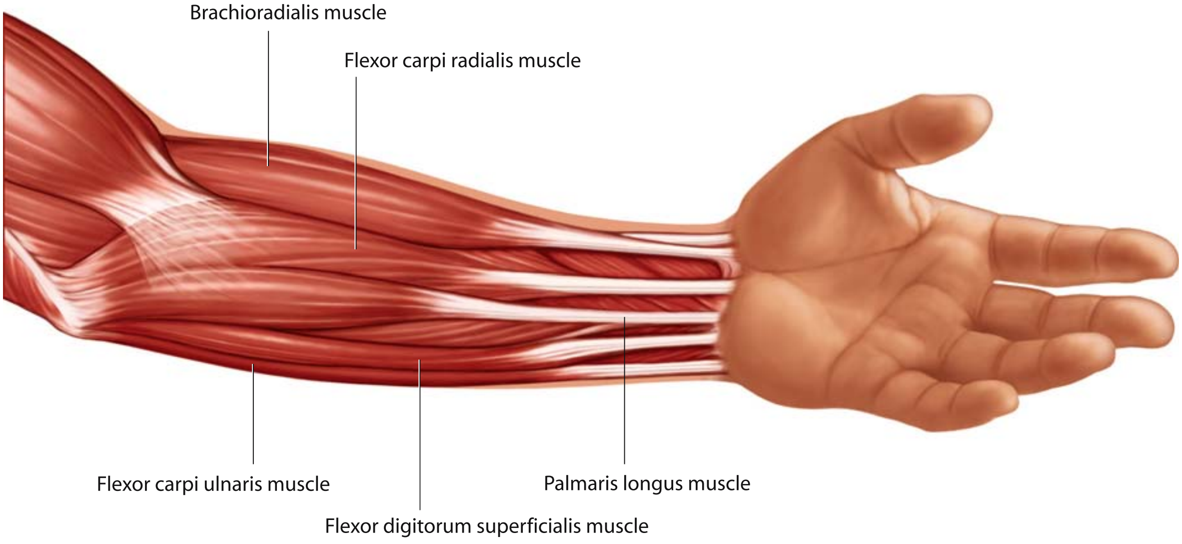
The vascular pedicle is traced proximally so that sufficient length for a safe anastomosis is obtained. Although it is possible to dissect the pedicle up to the brachial artery, this is seldom necessary. An excessively long pedicle can lead to kinking of the pedicle on the recipient side and cause vascular occlusion. Careful hemostasis must be performed at the pedicle to prevent diffuse bleeding after opening the anastomoses.

Step 14

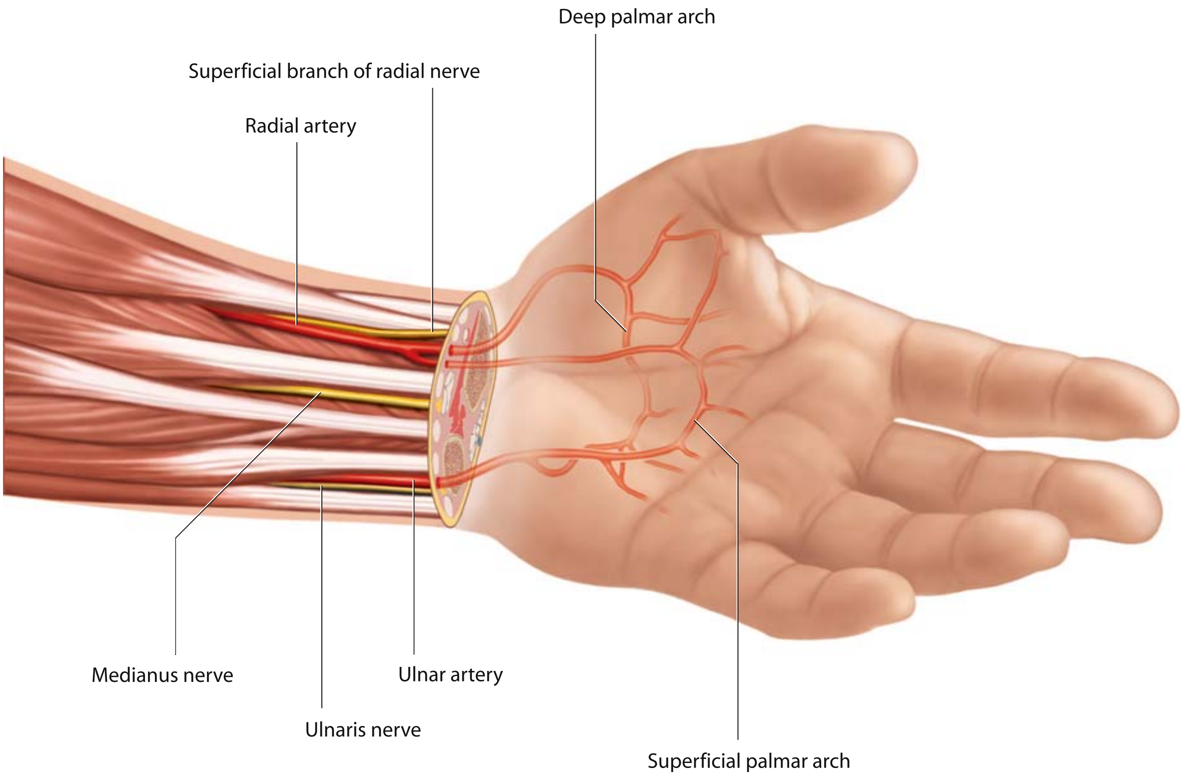
At the end of flap raising, residual connections between the flap and flexor carpi radialis tendon are transected at the flap hilum, and the vascular pedicle is completely freed from the donor site. Ligation of the pedicle is not performed until the recipient vessels are ready for anastomosis.

Step 15

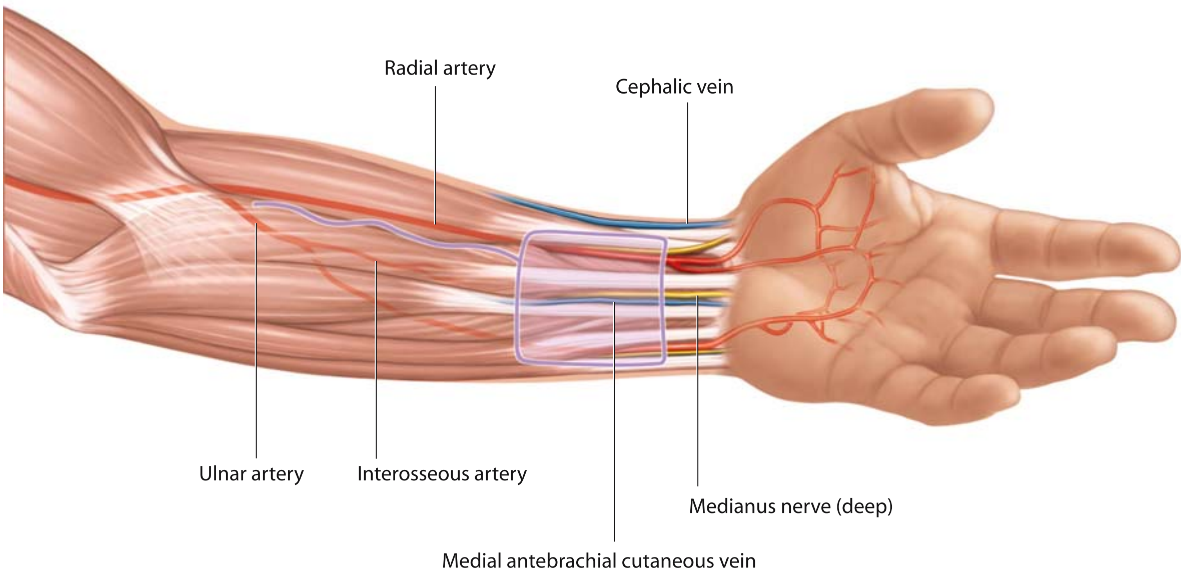
For reliable perfusion of the flap, anastomosing the radial artery and one of the deep radial veins is always safe and sufficient. Because the veins closely connected to the artery can be small in diameter, venous anastomoses need some microsurgical experience. The veins should be separated from the artery using the microscope. If a superficial vein is included, it can be used as additional venous drainage. The cephalic vein can be used as the only venous drainage when the flap has been extended to the dorsal aspect of the forearm so that it is safely located within the flap margins. If only a small flap is necessary, venous drainage through a cutaneous vein alone can become problematic because of the well-known anatomic variability of the superficial venous system.



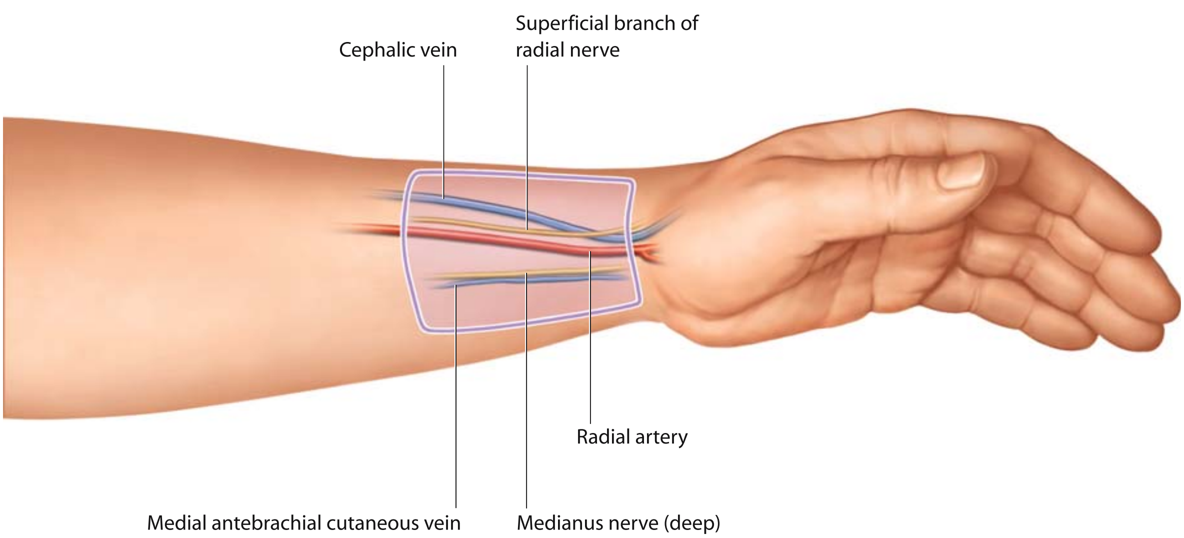
Flexor muscles of the forearm



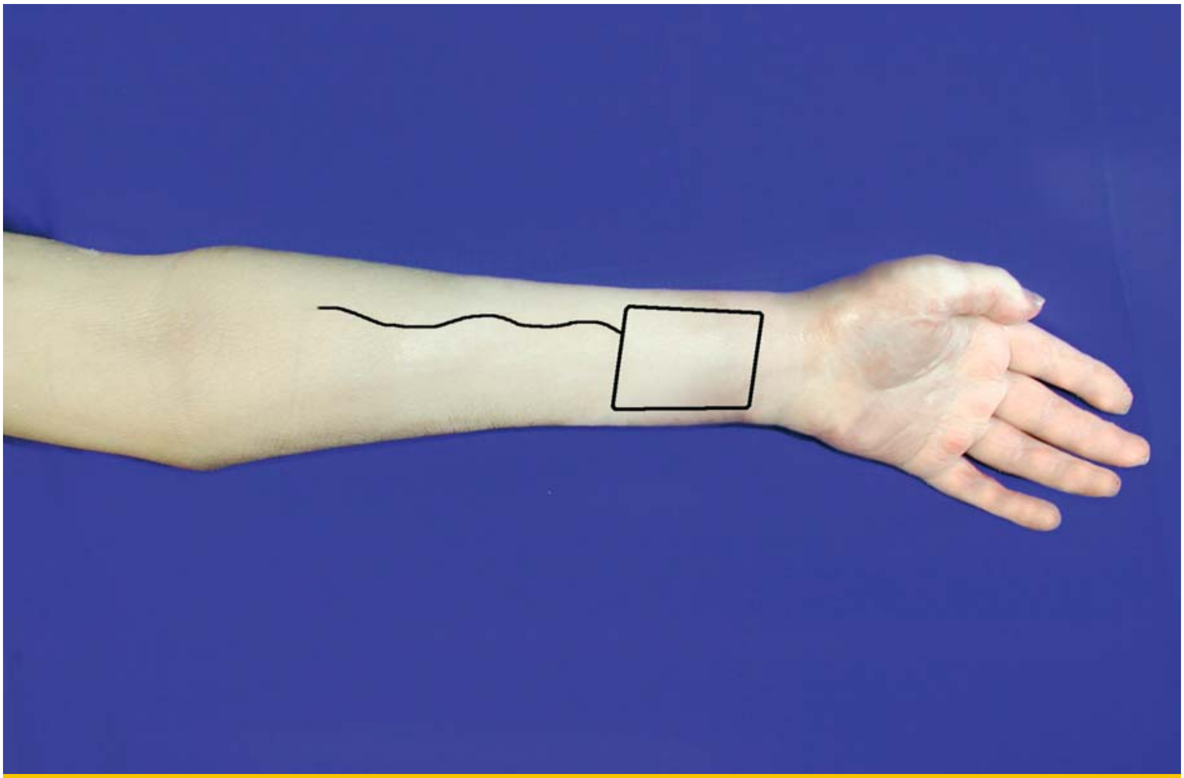
Vascular arches of the hand



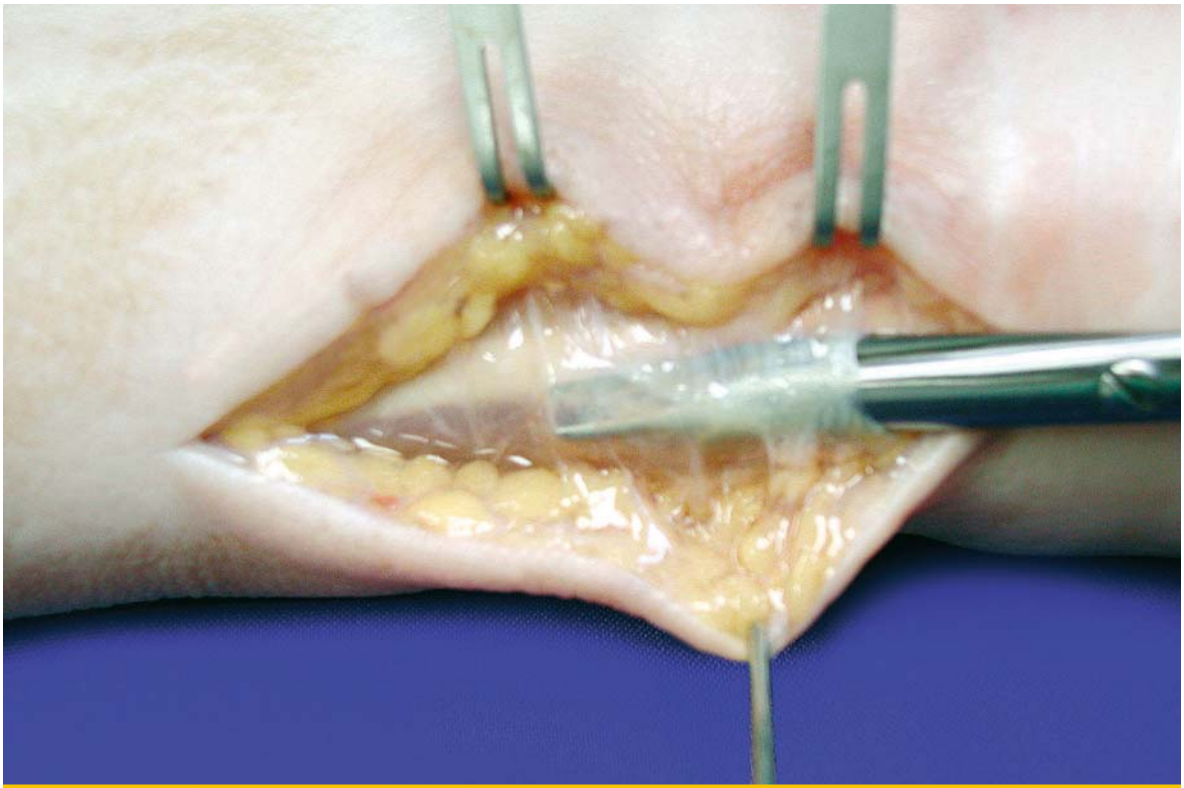
Standard flap design



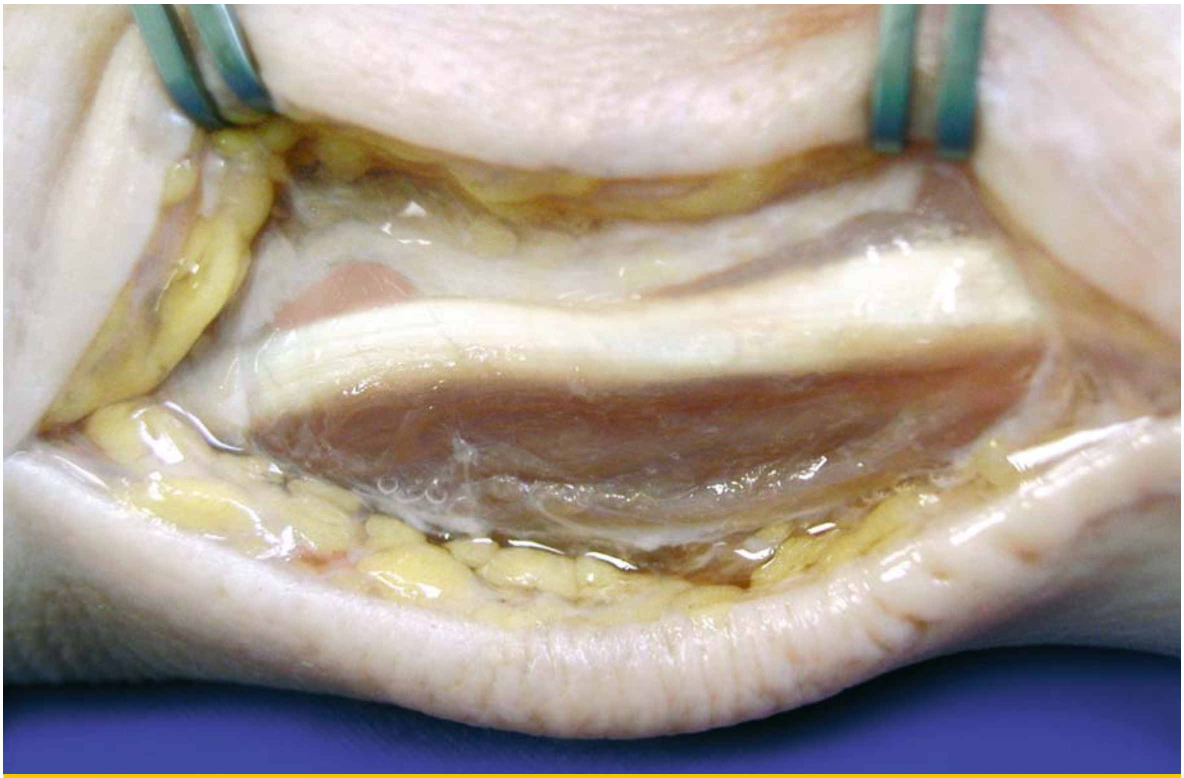
Dorsal extention for inclusion of the cephalic vein



Standard design of the radial forearm flap

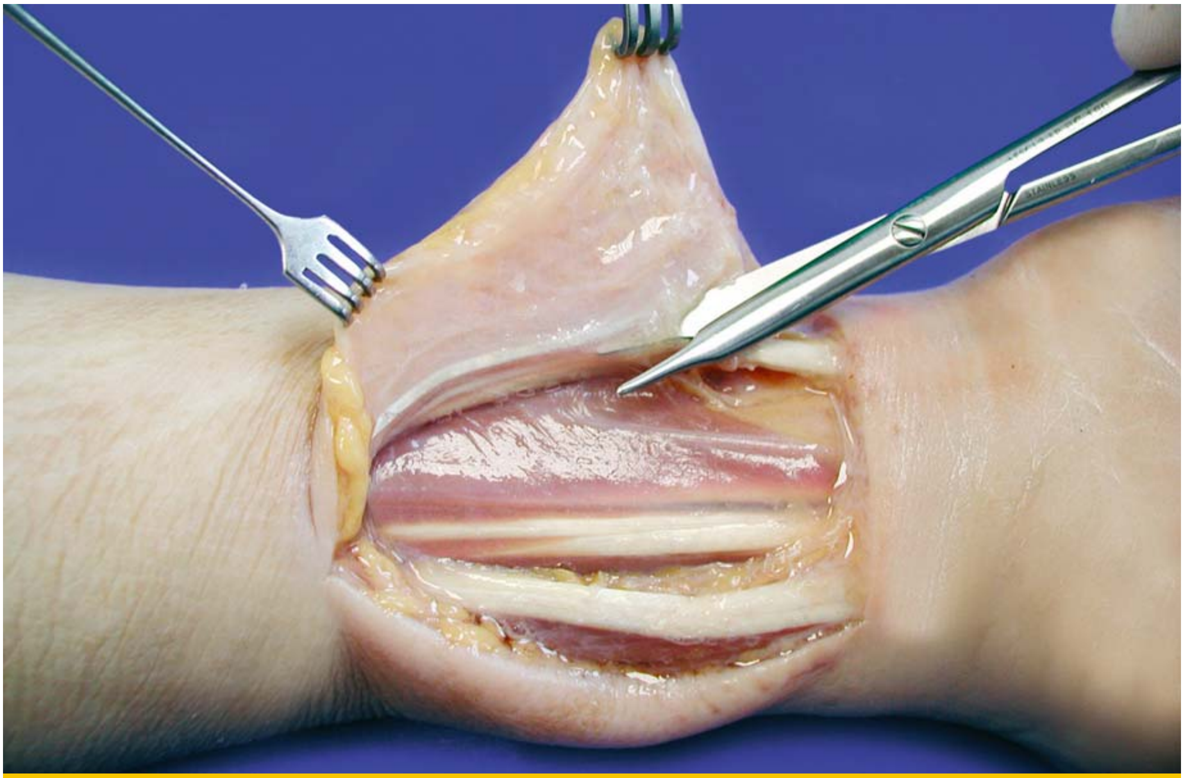


Step 1 • Ulnar skin incision and undermining of forearm fascia

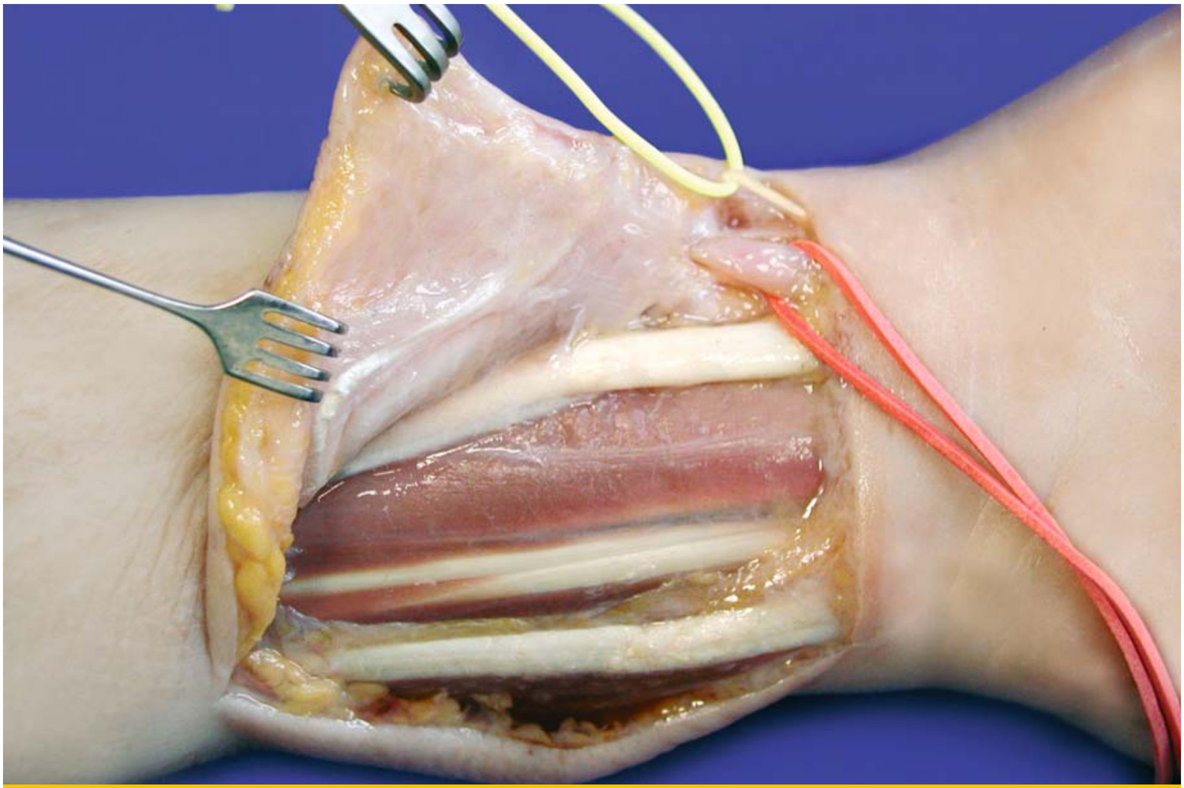


Step 2 • Incision of fascia and exposure of flexor carpi ulnaris

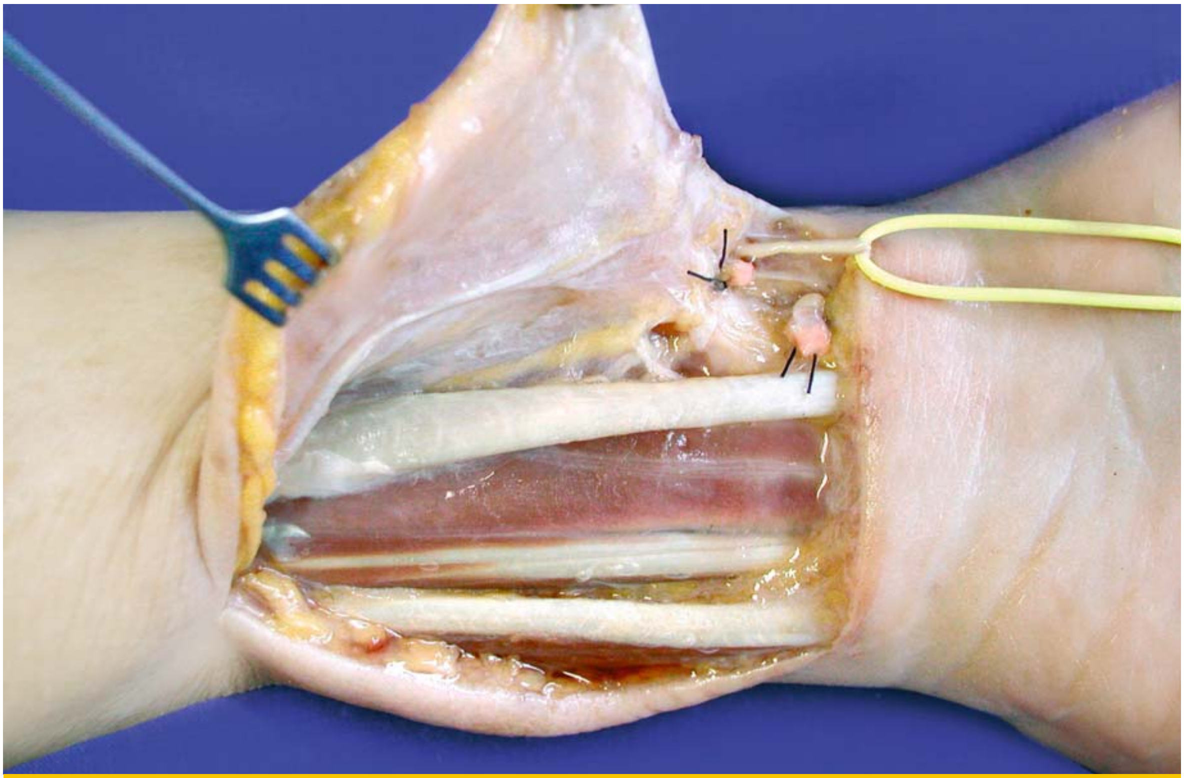
Step 3 • Distal skin incision, subfascial dissection



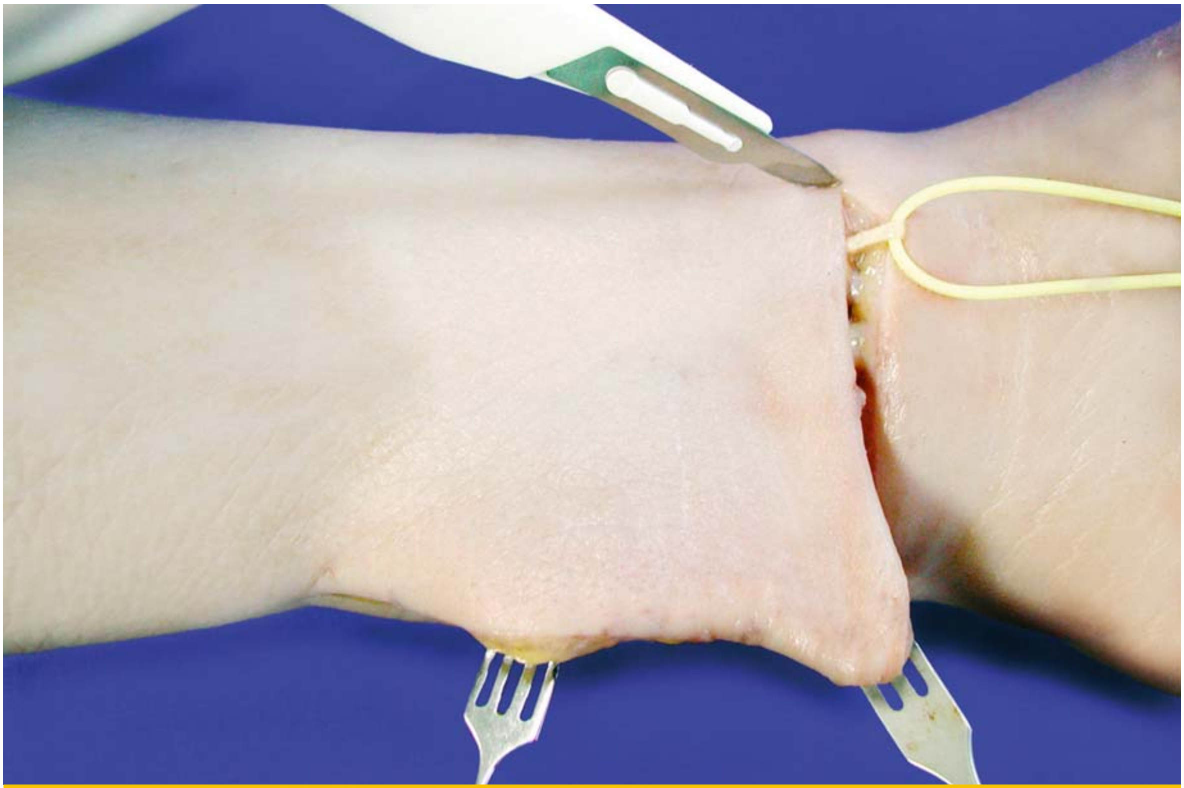
Step 4 • Exposure of the flexor carpi radialis tendon



Step 5 • Identification of radial vessels and superficial radial nerve at distal flap margin



Step 6 • Ligation of radial vessels at distal flap border

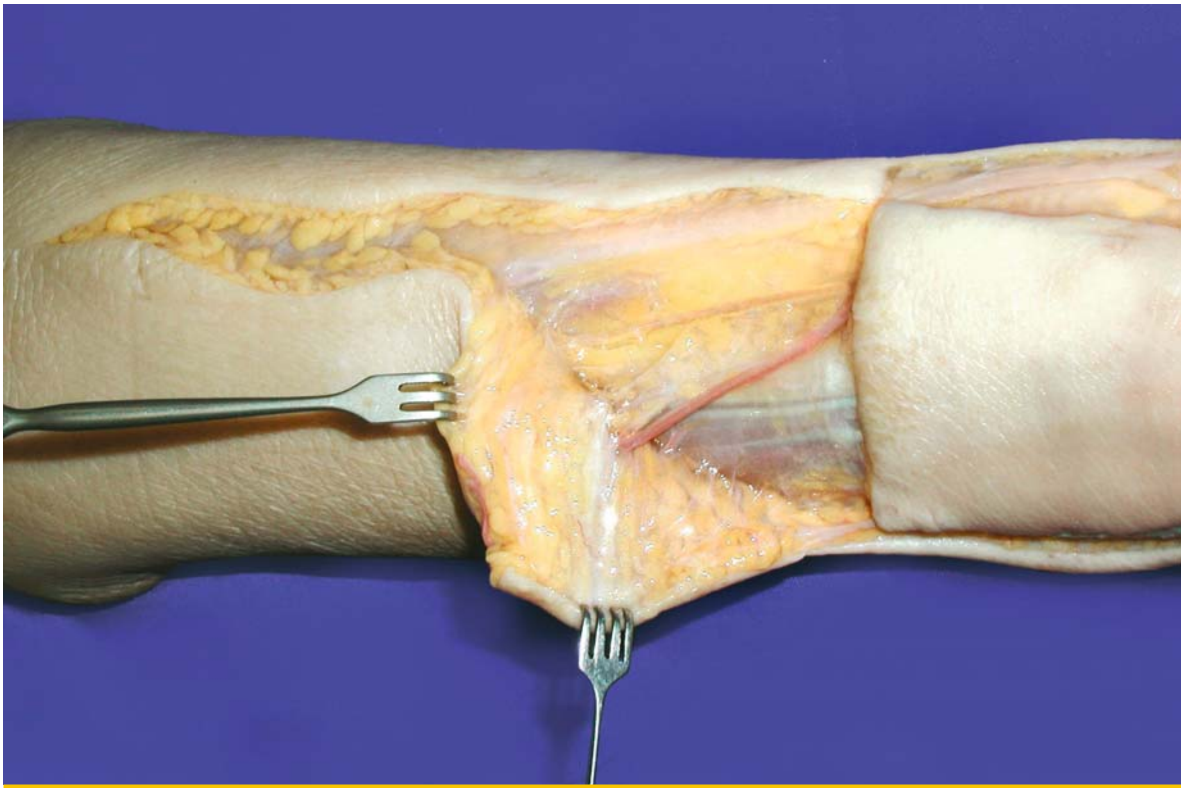


Step 7 • Radial skin incision

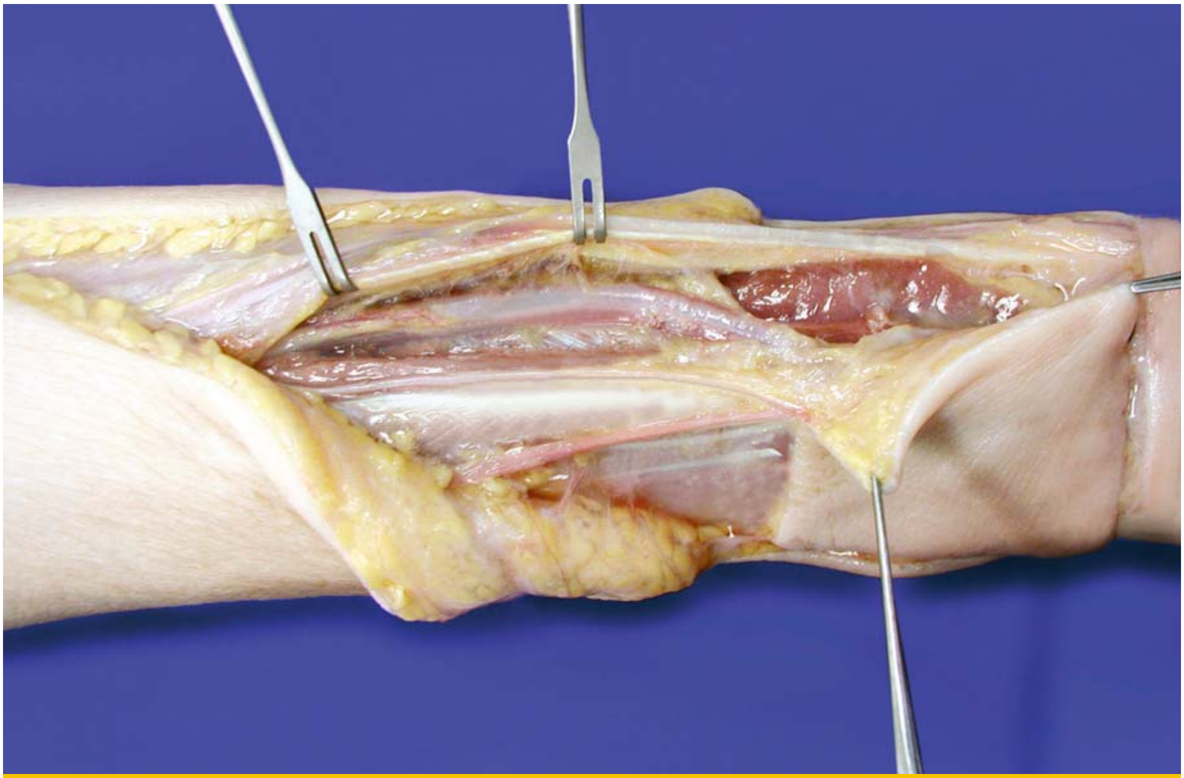
Step 8 • Dissecting the pedicle along brachioradialis muscle

Step 9 • Complete subfascial flap elevation

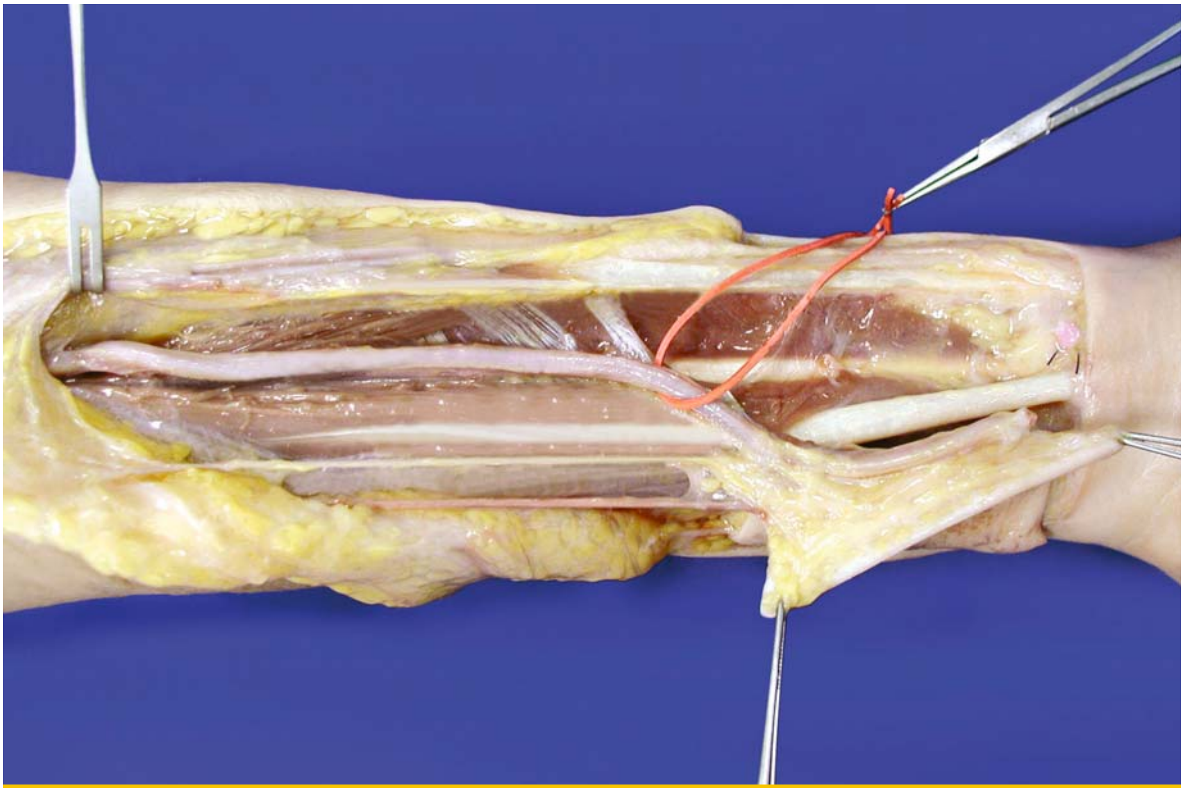
Step 10 • Skin incision at proximal flap margin and wavy incision for exposure of pedicle



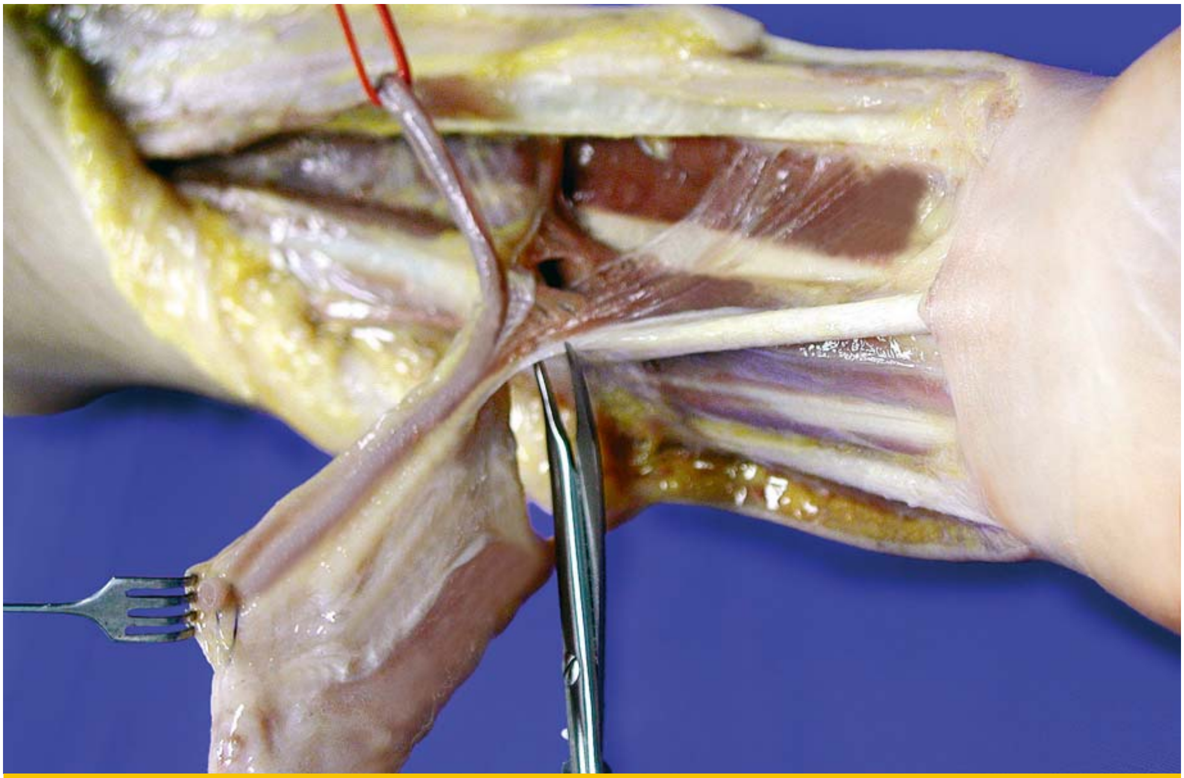
Step 11 • Exposure of additional superficial vein (optional)



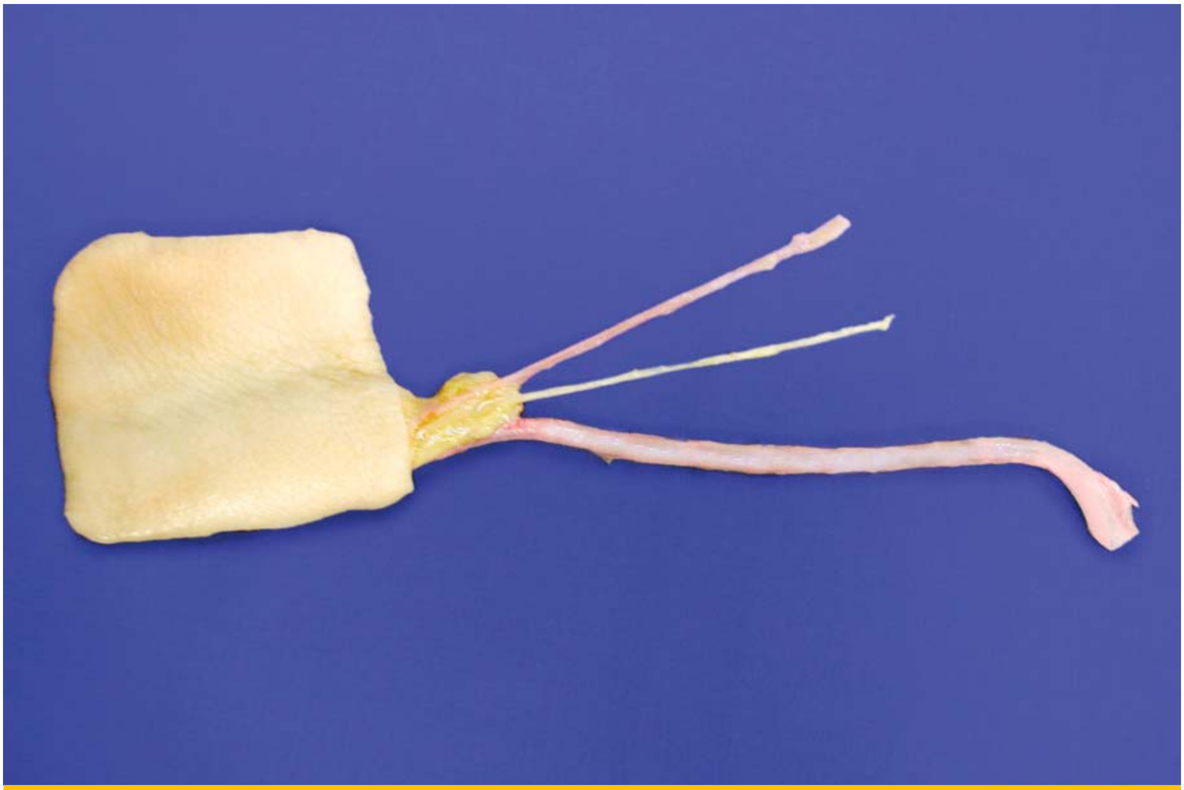
Step 12 • Exposure of vascular pedicle



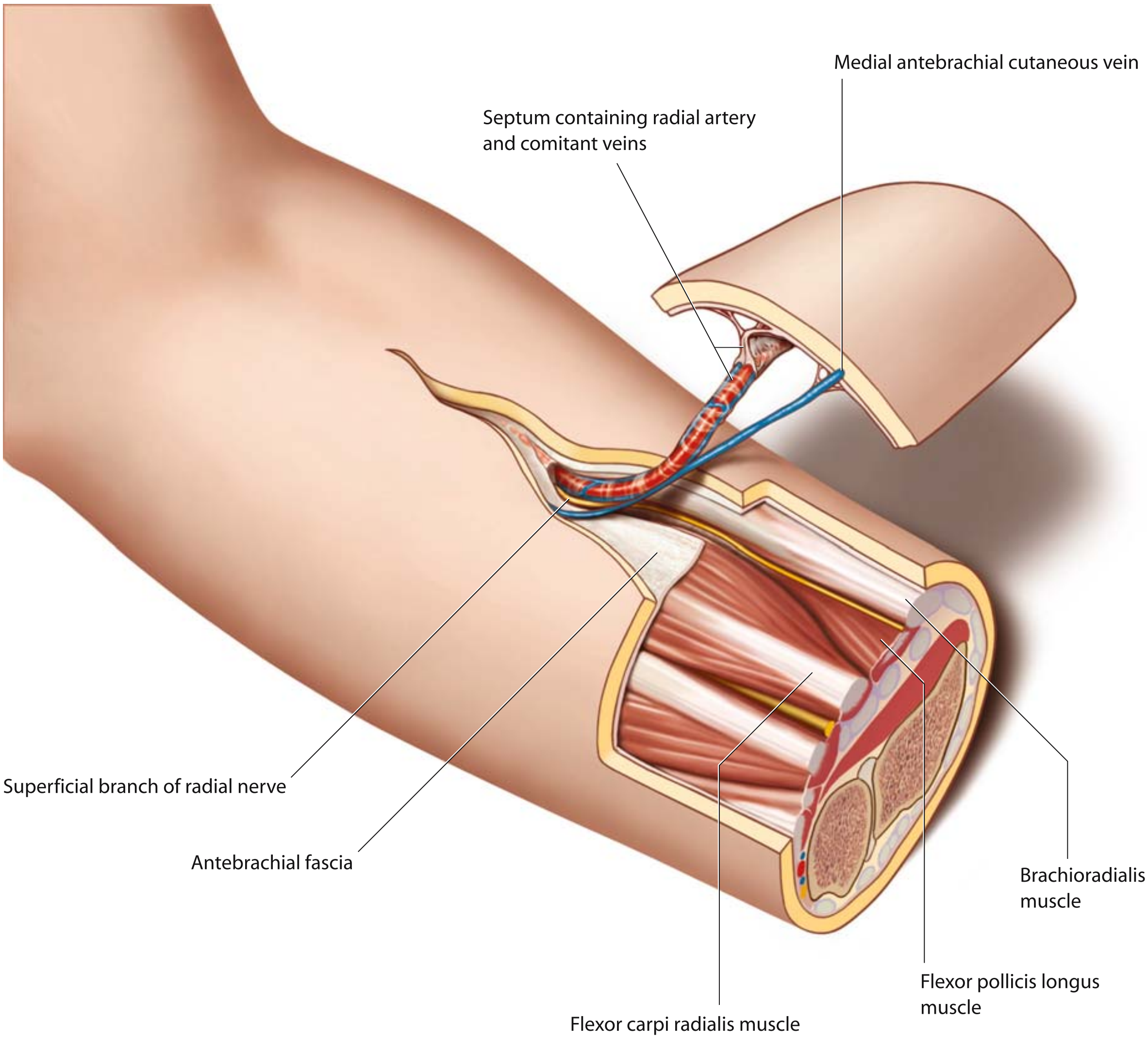
Step 13 • Complete dissection of pedicle



Step 14 • Separation of residual attachments at flap hilum



Step 15 • Flap raising completed with additional superficial vein and nerve



Cross section anatomy of left forearm

Comments

Step 2: To prevent using a false dissection plane above the fascia, incise the fascia until the underlying muscle becomes clearly visible. Advice: Do not dissect deep to the flexor carpi ulnaris muscle to prevent injury of the ulnaris artery. As a variation, the ulnaris artery can run superficial to the muscle (the ulnaris pulse can be palpated). If the ulnar artery is violated, raise an ulnaris flap instead of using the radial vessels.

Step 3: Do not remove the paratenon completely because this will lead to wound-healing disturbances. Advice: Fascia and paratenon can best be separated using a sharp scalpel.

Steps 5, 7: Injuring the superficial branch of the radial nerve is easily possible. In slim patients, the location of the nerve can be palpated through the skin. Including the cephalic vein can lead to damage of the superficial branch of the radial nerve with subsequent numbness at the dorsum of the thumb and index finger.

Step 8: Injuring the vascular pedicle is possible in this step; retract the brachioradialis muscle for dissection of the pedicle.

Step 11: Choosing an insufficient superficial vein as the only venous drainage will lead to venous congestion of the flap. Advice: Check the venous return of the superficial vein by cutting it at the end of flap raising before the radial artery is ligated.

After flap raising, the flexor carpi radialis tendon should be oversewn by muscle bellies for better take of the skin flap.

Chapter 2

Lateral Arm Flap

Development and Indications

The first septocutaneous flap was originally introduced in 1982 by Song and coworkers [240] and 2 years later was described in more detail by Katsaros et al. [126]. Similar to the radial forearm flap, the lateral upper-arm flap is relatively thin, but limited in width and can be transferred together with a segment of bone, muscle, or sensory nerves. The flap, which is raised at the lateral aspect of the upper arm, is perfused by the terminal branches of the profunda brachii artery. This artery is not essential for the vascularity of the extremity. Early clinical series document a number of application possibilities, especially in the head and neck area [53, 55, 165, 224, 230, 275]. Because of its texture and the favorable color match, the flap is well suited for replacement of the facial skin [240]. At the extremities, the upper-arm flap is useful for defect cover on the foot, hand, or forearm as a free flap [142, 177, 187, 220, 275] or as a pedicled flap for coverage of defects at the shoulder region [55; 275]. For defect cover at the temporal region, Inoue and Fujino left the flap pedicled on the cephalic vein, whereas the flap artery was microsurgically anastomosed to a neck artery[117]. In addition to these indications, the lateral upper-arm flap can be used for a number of intraoral reconstructions. Matloub and coworkers reported on six reconstructions following partial or total glossectomy or defect cover at the hard palate [165]. By connecting the posterior cutaneous nerve of the arm to the lingual nerve, they achieved neurocutaneous reinnervation. Including a cortical segment of the humerus, a limited amount of bone can be harvested together with the skin paddle, which was used for lower-jaw reconstruction [165; 275]. Other authors have confirmed the usefulness of the lateral upper-arm flap for intraoral reconstructions in larger clinical series [46, 95, 197], especially the high success rate of neurocutaneous reinnervation after nerve coadaptation [46]. When extending the flap to the proximal forearm, the thin and pliable forearm skin can be combined with the thicker flap portion of the upper arm [46]. Moffett and coworkers demonstrated the possibility of dividing the flap, which then can be used for closure of perforating defects of the oral cavity [176].

Anatomy

The lateral upper-arm flap is nourished by septocutaneous branches of the posterior radial collateral artery (PRCA), which develops from the profunda brachii artery. The cutaneous branches of the flap rise to the skin within the lateral intermuscular septum, which separates the brachialis from the triceps muscles. According to Myong, the profunda brachii artery branches off from the brachial artery as a singular vessel in 52 %, or together with the ulnar collateral artery in 30 % [183]. In 8 %, the vessel branches off directly from the axillary artery. Different studies describe a double profunda brachii artery with an incidence of 4–12 % [126, 176, 203]. In these rare cases, each of the arteries has to be temporarily occluded to test its contribution to flap perfusion [176]. The proximal diameter of the artery varies from 0.9 to 2.5 mm [53,126,183], measuring 1.2 [165] or 1.5 mm on average [53, 126]. In close proximity to the radial nerve, the vascular pedicle spirals around the humerus, and proximal to the lateral intermuscular septum, it divides into the small anterior and the stronger PRCA. Whereas the small anterior radial collateral artery travels together with the radial nerve, the PRCA is the main nutrient artery of the flap, giving off the septocutaneous branches. After traversing the septum at its base, the PRCA anastomoses with the recurrent radial artery, on which the flap can be perfused in a retrograde fashion. Because the proximal segment of the profunda brachii artery runs underneath the long and lateral head of the triceps muscle, dissection of the vascular pedicle to a proximal direction can be difficult. The average length of the pedicle that is not covered by the triceps muscle is thus 7–8 cm [165, 176]. By longitudinally splitting the above triceps heads, the profunda brachii artery and veins can be followed up to the brachial vessels, obtaining a 6–8 cm longer pedicle [176]. It should be mentioned that this maneuver can lead to reduced strength in the arm being operated upon, possibly following injury of muscular branches of the radial nerve [176]. The posterior cutaneous nerve of the arm (PCNA), which accompanies the PRCA and always has to be sacrificed during flap elevation, can be used to create sensate flaps [165, 187, 240, 275]. The posterior cutaneous nerve of the forearm (PCNF) does not provide innervation to the flap and could be preserved during flap elevation, but for technical reasons this nerve is normally sacrificed, too. Venous drainage is most reliable by the concomitant veins of the profunda brachii, because the course of the cephalic vein is usually too medial in the upper arm [187]. When outlining the skin paddle, the flap axis is positioned along the intermuscular lateral septum, which is defined by the interconnecting line between the lateral epicondyle and deltoid insertion. Although the skin territory can be as large as 18 × 11 cm [165], flaps should always be located within the "zone of security," extending 12 cm proximal to the lateral epicondyle and including one-third of the circumference of the upper arm [203, 275]. According to anatomical studies using dye injections, distal extension of the flap is possible up to 8 cm inferior of the lateral epicondyle [139]. It is technically possible to harvest a cortical segment of humerus, but only to a size of 10 × 1 cm, leaving a muscle cuff on either side of the septum to include periosteal vessels of the PRCA [53]. Direct closure of the donor site is only possible if the width of the flap does not exceed 6 cm. For aesthetic reasons, the use of a skin graft should be avoided in this area [187].

Advantages and Disadvantages

The lateral upper-arm flap has a reliable and constant anatomy, and because of the good color match and similar texture, the flap is suitable for defect coverage in the face and neck. Compared to the radial forearm flap, the raising of this flap is technically more demanding because of the deeper location of the pedicle and its close relationship to the radial nerve. Although in normal-weight patients the flap only has a thin layer of subcutaneous fat, the average thickness of the adipose layer is 1.3 cm [81], and a considerable amount of subcutaneous fatty tissue can be found in adipose patients [187]. The possibility of creating sensate flaps is considered to be an advantage, especially in tongue reconstructions [165]. The combination of the skin paddle with a segment of the humerus bone or triceps muscle may help provide a wider indicational spectrum for this flap [53, 126] but better flaps are available for reconstruction of composite tissue defects. The highly reliable vascularity of the fascia allows pure fascial flaps to be raised that can be covered with split-thickness skin grafts [240]. These fascial flaps have proven to be useful in reconstructions of the ear and nose [46]. The main disadvantage of the flap is the limited length of the pedicle and the small diameter of the vessels, so that anastomoses can be difficult, especially following radical neck dissection [176, 187, 275]. Flap raising leads to loss of sensation at the proximal and posterior aspect of the forearm, but this is usually well tolerated by the patients. Although there is no functional limitation in the donor arm, strength and extension can be objectively reduced after transection of the triceps head. Another disadvantage is the limited width of the flap, so that another donor site should be considered if a broad flap is needed. As a solution to this problem, Katsaros proposed that a long flap be divided and both skin islands positioned adjacent to each other, so that the flap width is doubled and the donor site still can be closed directly [126]. Another possibility to overcome this problem is pretransfer skin expansion [230], but this technique cannot be performed in patients with malignant tumors needing primary reconstruction.

Flap Raising

Patient Positioning

The upper arm is disinfected completely from the shoulder and axilla down to the distal forearm and brought into an abduced position. The elbow is moderately flexed. In this position, flap raising can be carried out simultaneously to tumor resection in the head and neck area. No specific preoperative measures are necessary for elevating the lateral arm flap, and there is no need to use a tourniquet.

Standard Flap Design

For most indications, the flap dimensions vary between 7 and 12 cm in length and 5–6 cm in width. The central axis of the skin island lies over the septum between the brachial and triceps muscle (lateral intermuscular septum), which is represented by the interconnection of the lateral epicondyle and the insertion of the deltoid muscle. The skin paddle covers the brachial and part of the biceps muscle anterior and the lateral head of the triceps muscle posterior to the septum with a maximum width of 7 cm. The distal pole of the flap is outlined 1–2 cm proximal to the epicondyle, and the proximal pole is placed 4–6cm below the deltoid insertion. An incision between the proximal flap pole and insertion of the deltoid muscle is made for exposure of the proximal vascular pedicle.

Flap Raising

Step 1

At the posterior circumference of the flap, the skin incision is made perpendicularly through the subcutaneous fatty tissue until the brachial fascia is reached. During the whole flap-raising procedure, the skin paddle may not be separated from the underlying fascia, which forms the intermuscular septum and thus contains the septocutaneous flap vessels.

Step 2

After the fascia is identified, it is incised at the posterior periphery of the flap, and the lateral head of the triceps muscle is exposed. By careful elevation of the fascia, the dissection proceeds bluntly in an anterior direction until the lateral intermuscular septum is reached. This septum separates the triceps from the brachial muscle. On the surface of the septum, the septocutaneous perforating vessels from the posterior radial collateral artery (PRCA) become visible.

Step 3

Flap raising is continued at the anterior margin of the flap, where the brachial fascia is identified and then incised. In the subfascial plane, the flap is now undermined until the anterior aspect of the lateral intermuscular septum has been reached. The brachioradial muscle, which partly originates from the distal part of the septum, and the brachial muscle are exposed. In addition to the septocutaneous perforators, which also become visible at the anterior aspect of the septum, the fascia contains the posterior cutaneous nerve of the forearm (PCNF). This branch of the radial nerve provides sensation distal to the lateral epicondyle at the forearm and is sacrificed during flap raising.

Step 4

In the close-up view, three perforating vessels can be seen arising from the base of the intermuscular septum to the skin. The PRCA, from which the perforators branch off, travels along the base of the septum distally where it anastomoses with the recurrent radial artery. It is accompanied by the PCNF, which later is transected during flap raising. The base of the septum is still firmly attached to the humerus bone.

Step 5

Before the septum is incised distally, the strong radial nerve is palpated anterior to the septum between the brachioradial and brachial muscle. The nerve is exposed at the distal third of the upper arm by careful and blunt separation of the muscle fibers. The nerve is accompanied by the anterior radial collateral artery, which does not contribute to flap perfusion. After the nerve is identified, it can easily be protected during the separation of the lateral intermuscular septum from the humerus bone.

The intermuscular septum is perpendicularly incised at the distal flap pole to the level of the periosteum. The flap is elevated and the base of the septum becomes visible. Here, the PRCA and the PCNF are transected and ligated at the distal end of the septum directly over the periosteum of the humerus bone. Step 6

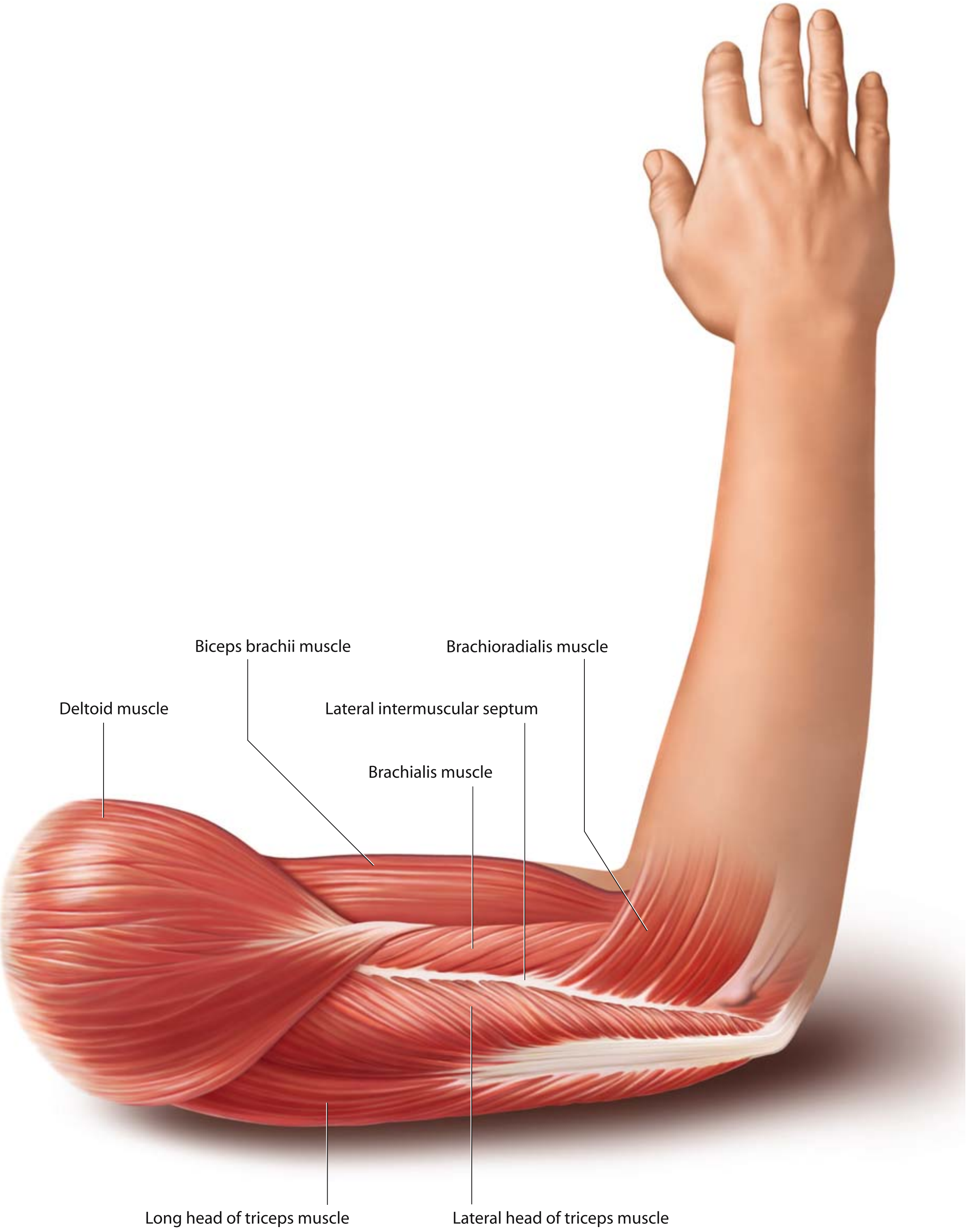
Now, the base of the intermuscular septum, which contains the PRCA, is separated from the humerus. Doing this, care must be taken not to miss the pedicle that runs close to the bone. Therefore it is recommended that the dissection be performed directly at the level of the periosteum. With direct visualization of the radial nerve, this is possible without any risk of injury to either the radial nerve or the vascular pedicle. If the scissors are always in contact with the periosteum, the right dissection plane can be maintained. Step 7

Flap elevation is continued in the cranial direction, where the vascular pedicle is still covered by the bellies of the brachial and triceps muscle. Before dissection of the pedicle is continued, the PCNA is revealed, which branches off from the radial nerve to enter the septum and ramifies in the subcutaneous tissue of the flap. Together with the PRCA, this cutaneous nerve represents the neurovascular pedicle of the flap. Step 8

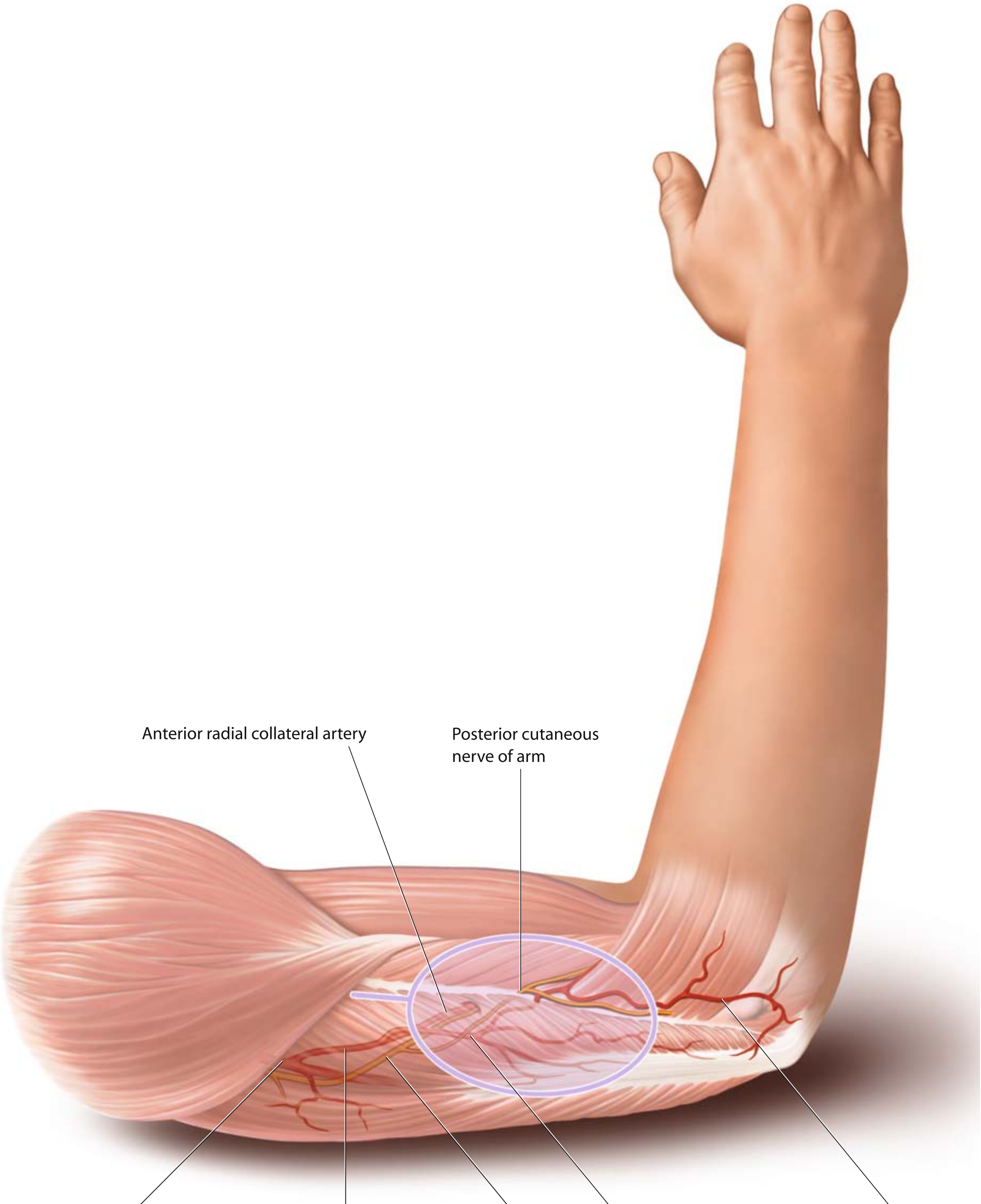
In the close-up view of the neurovascular hilum it can be seen that the radial nerve, the PCNA, and the vascular pedicle run close together, so that proximal dissection of the pedicle must now be performed with great care to prevent injury to the radial nerve. Step 9

For further exposure of the pedicle, the septum is transected at the superior pole of the flap while the neurovascular pedicle is carefully protected. The flap is now completely elevated, and the PRCA, which is mostly accompanied by two veins, is traced in the proximal direction along the spiral groove of the humerus. Step 10

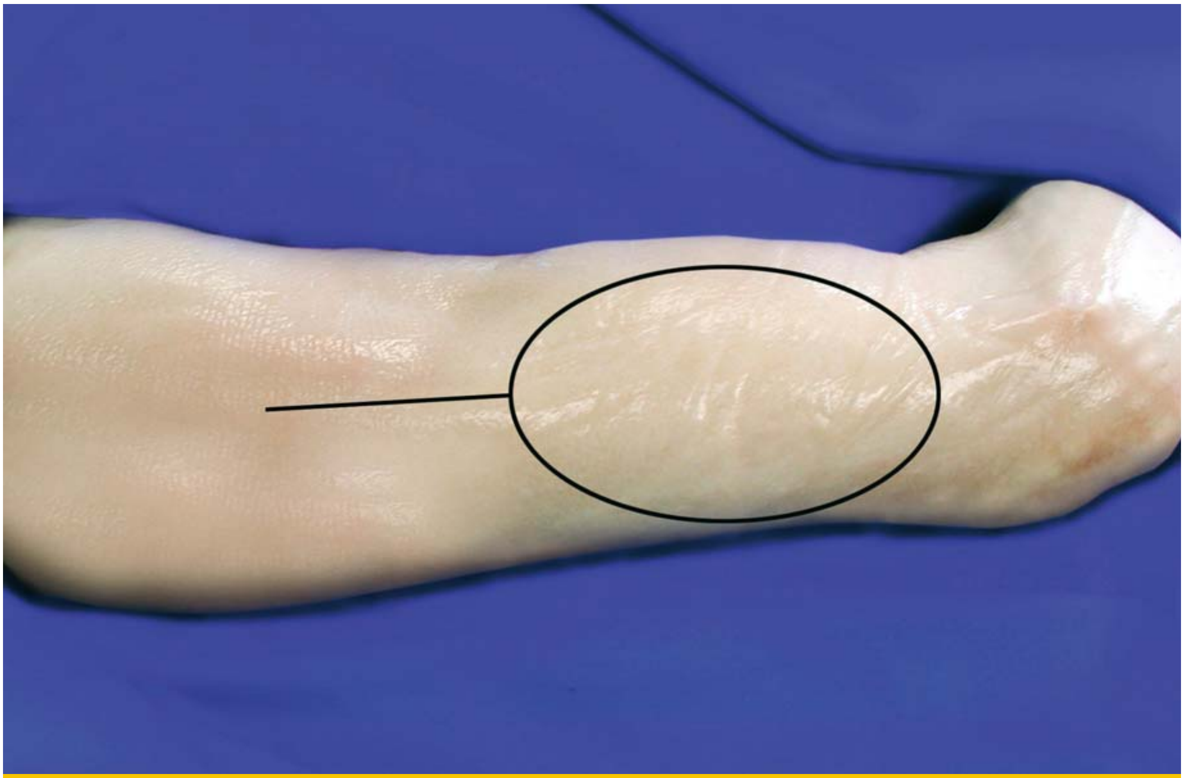
To lengthen the pedicle up to the brachial artery, the dissection can be extended proximally between the lateral and long heads of the triceps muscle. To this end, these muscles must be split to reach the takeoff of the profunda brachii artery from the brachial artery. Using this technique, it is important to preserve the branches of the radial nerve to the triceps muscle. If the standard pedicle length of 6–8 cm is sufficient, the dissection ends where the fibers of the lateral head of the triceps limit further exposure of the profunda brachii artery along the spiral groove. At the proximal end of the pedicle, the concomitant veins are bluntly separated from the artery. The PCNA must always be transected at the cranial flap pole and can be used for neurocutaneous reinnervation. Direct wound closure can be accomplished if the width of the flap does not exceed 6–7 cm. Step 11



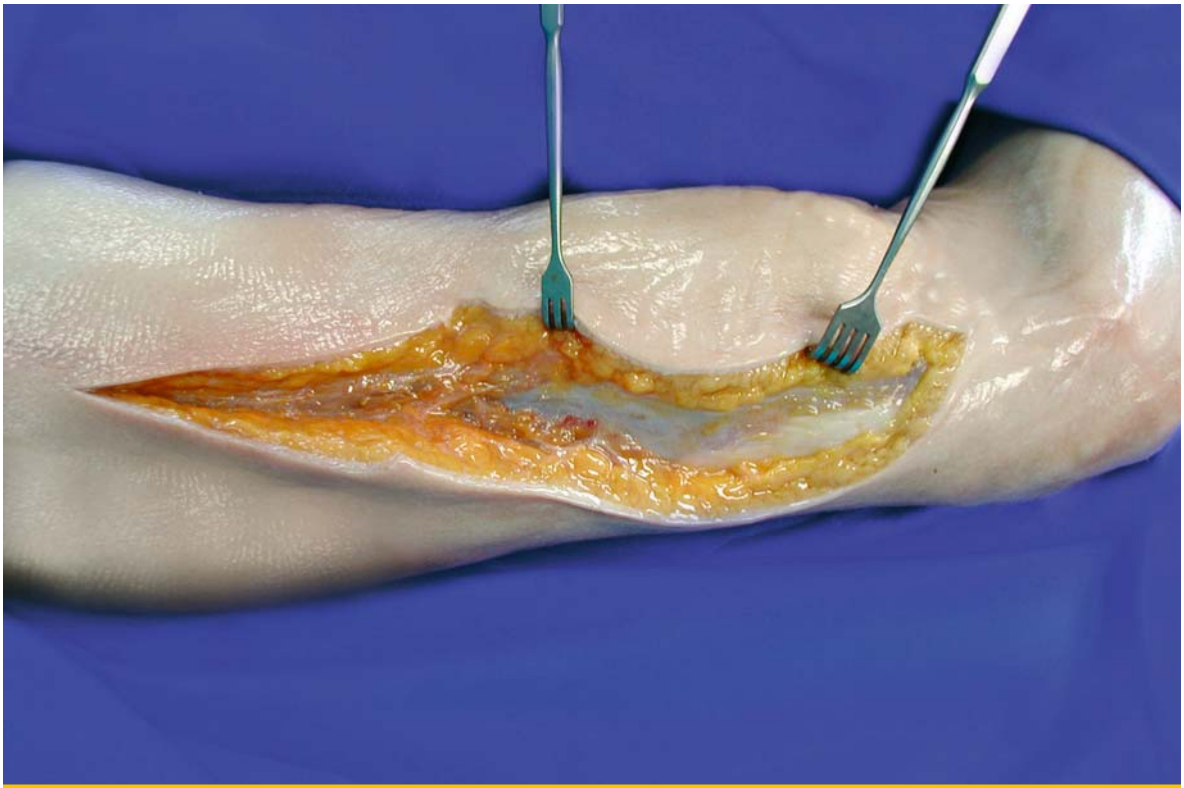
Muscles of the upper arm



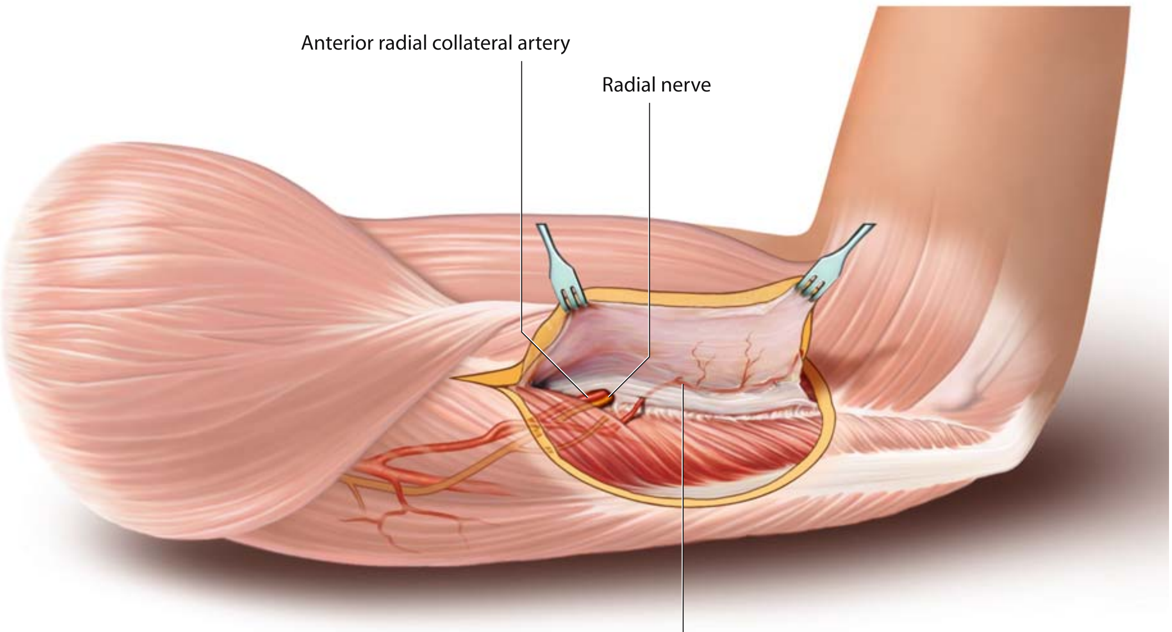
Vascular system and standard design of the lateral upper arm flap

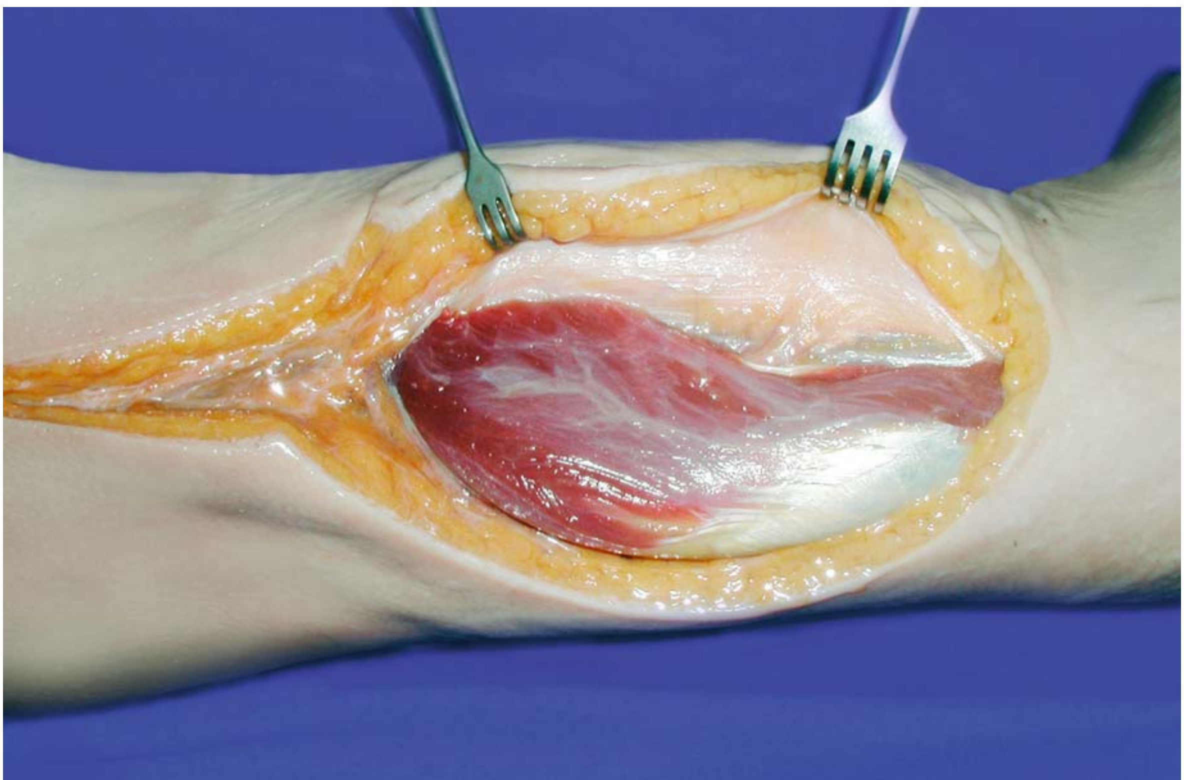


Position of standard skin paddle

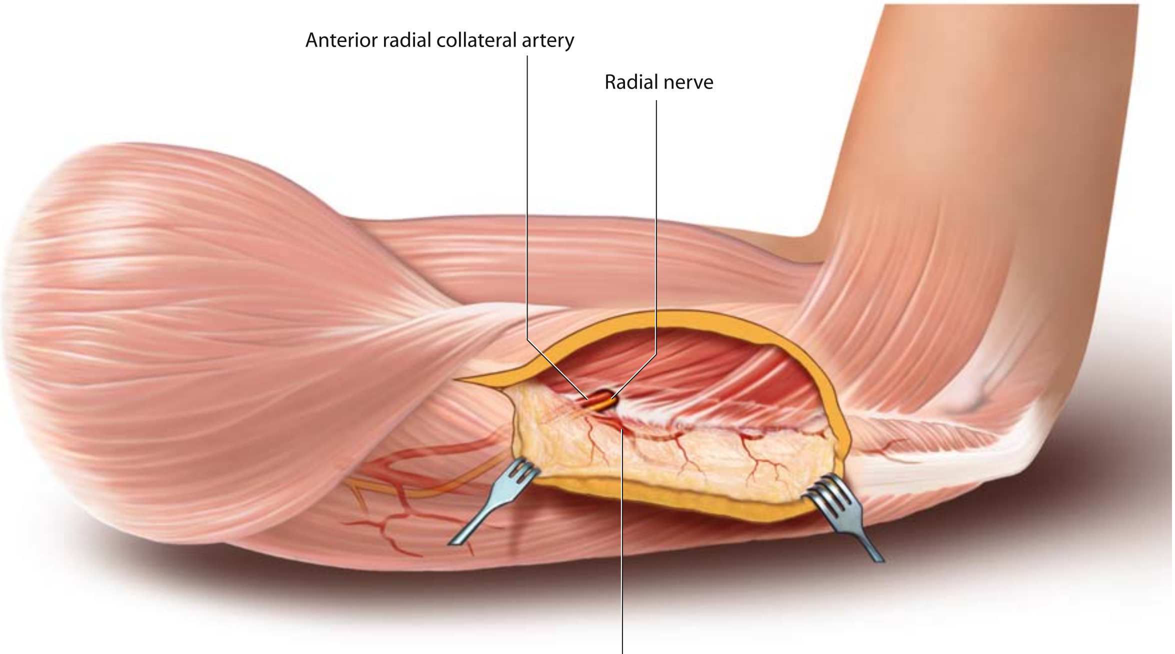


Step 1 • Incision through skin and fatty tissue

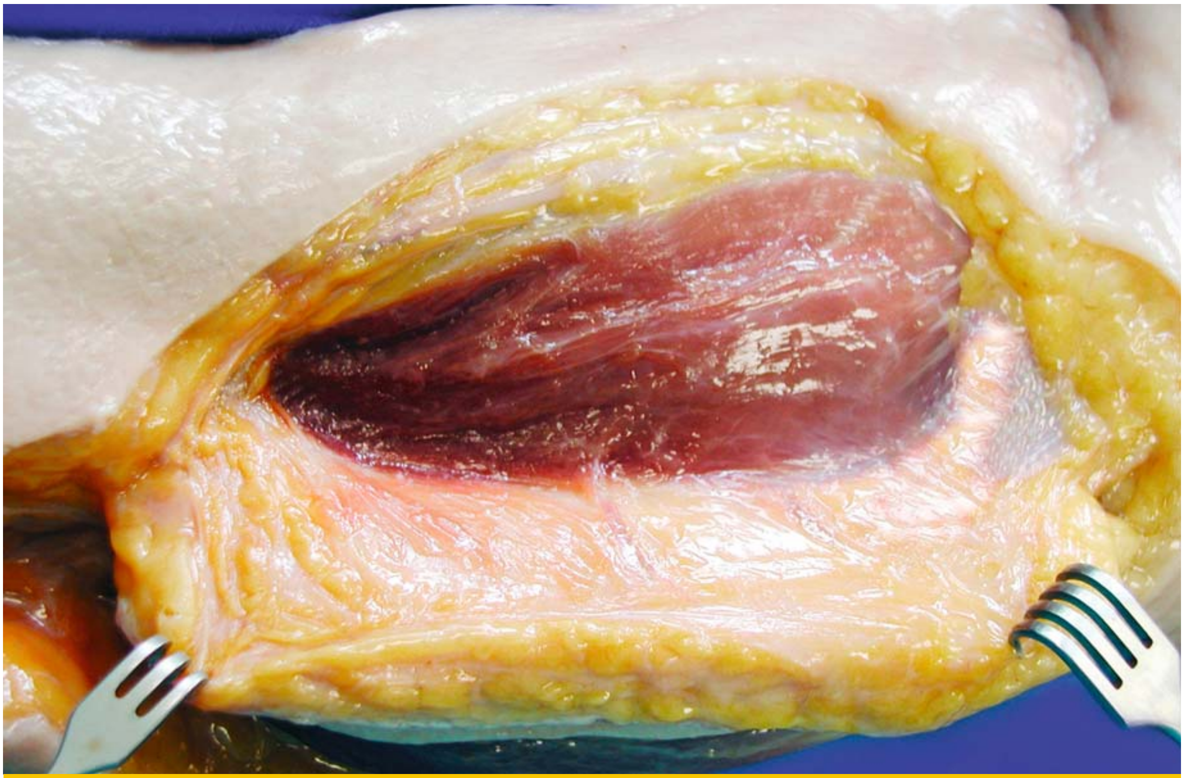




Step 2 • Incision of fascia, exposure of lateral head of triceps and septum

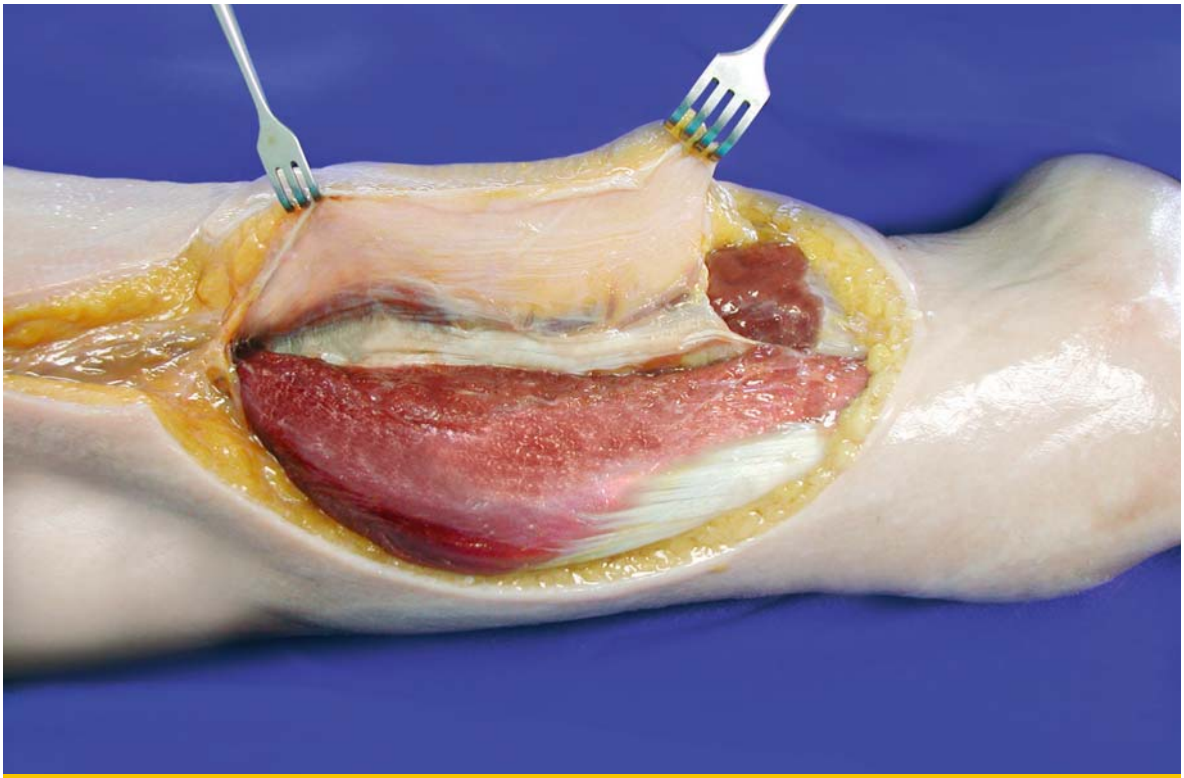


Step 3 • Identification of lateral intermuscular septum from anterior approach

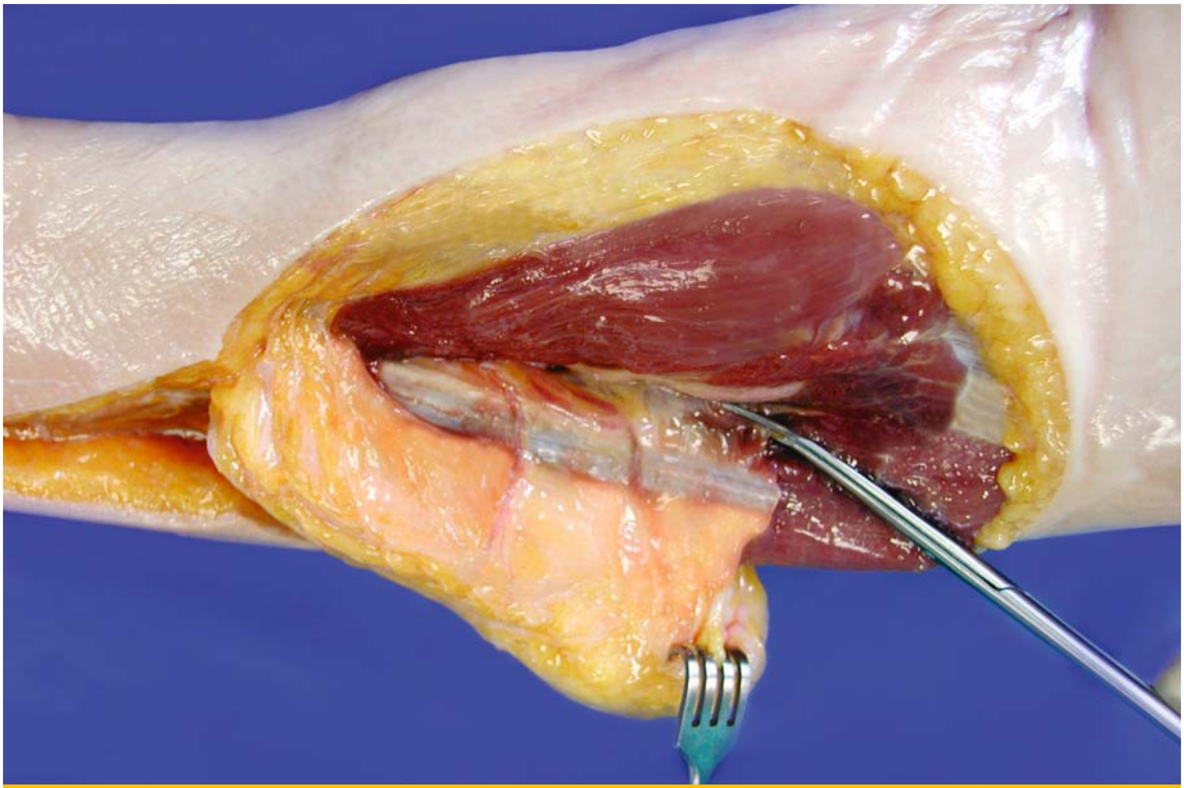


Step 4 • Identification of septocutaneous perforators

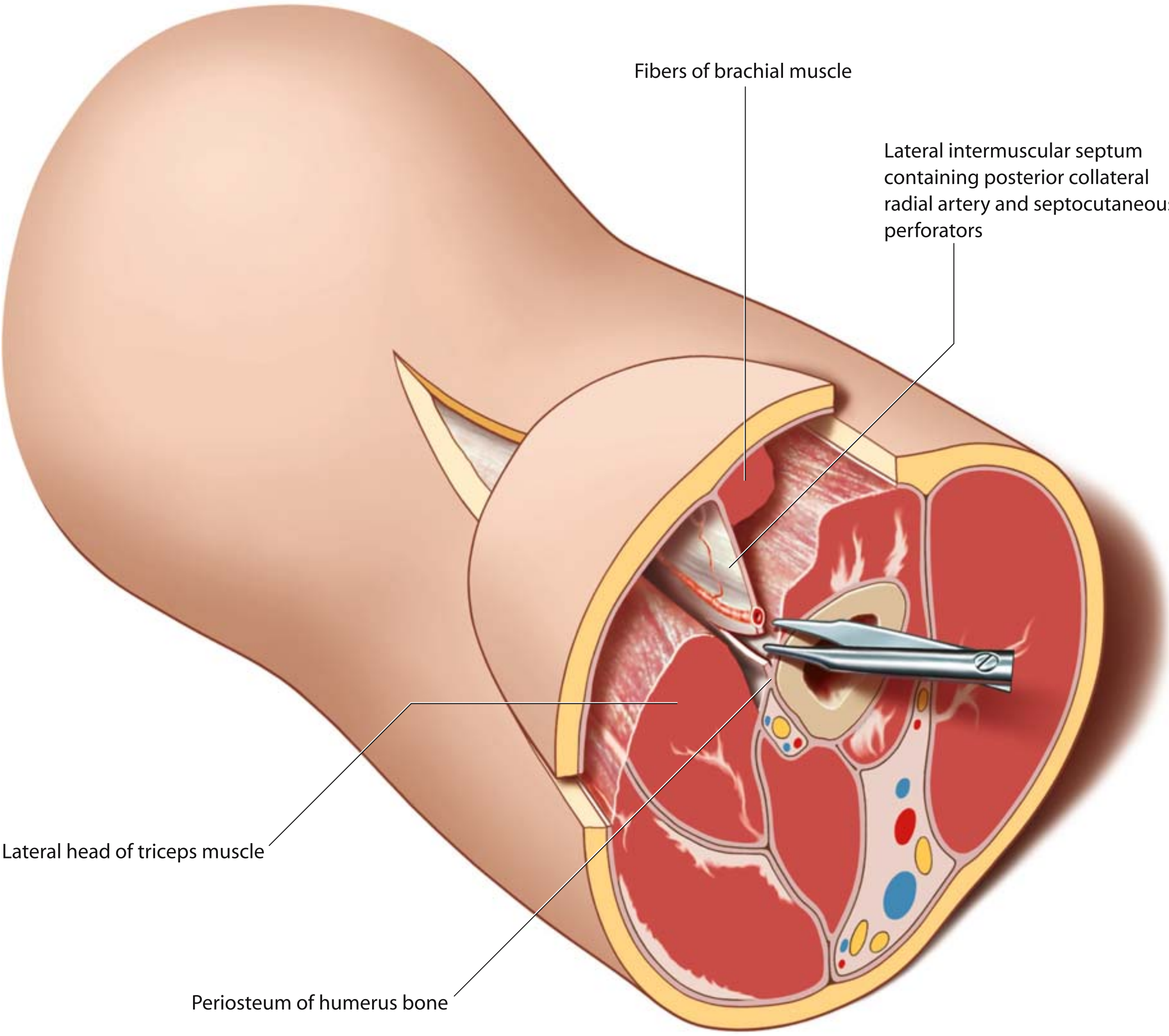
Step 5 • Exposure of radial nerve



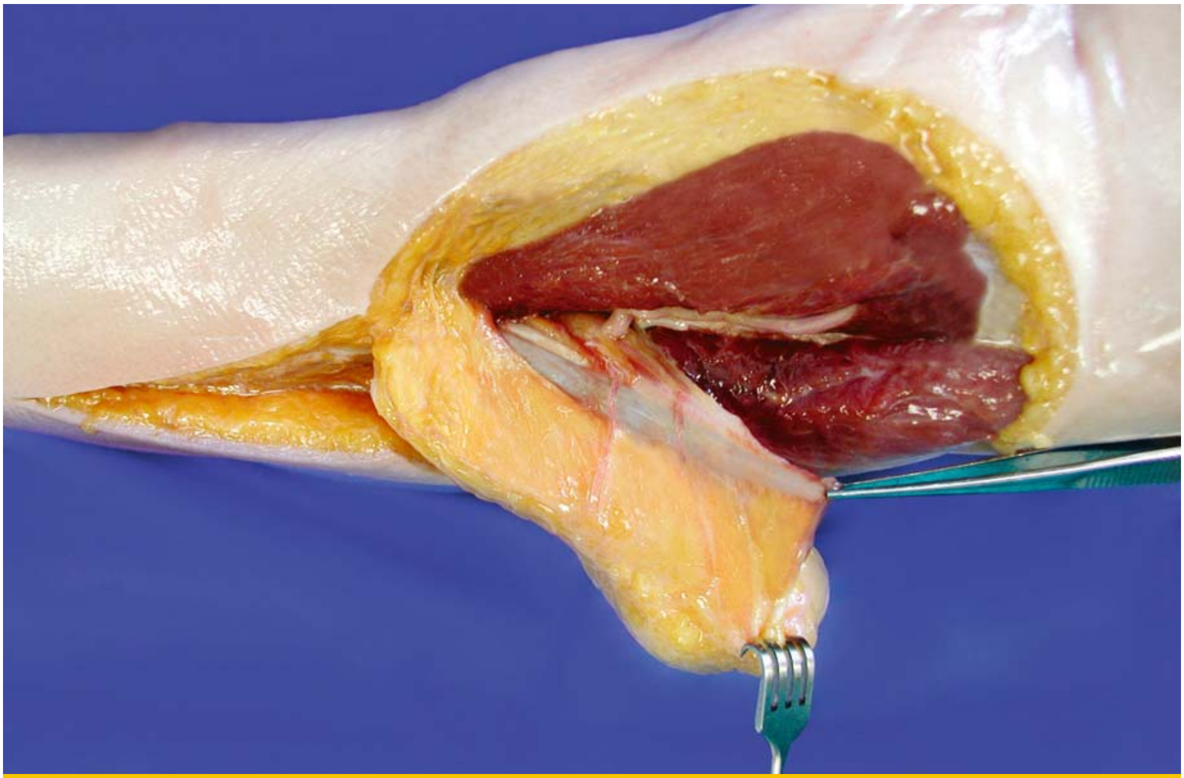
Step 6 • Transection of distal pedicle and septum



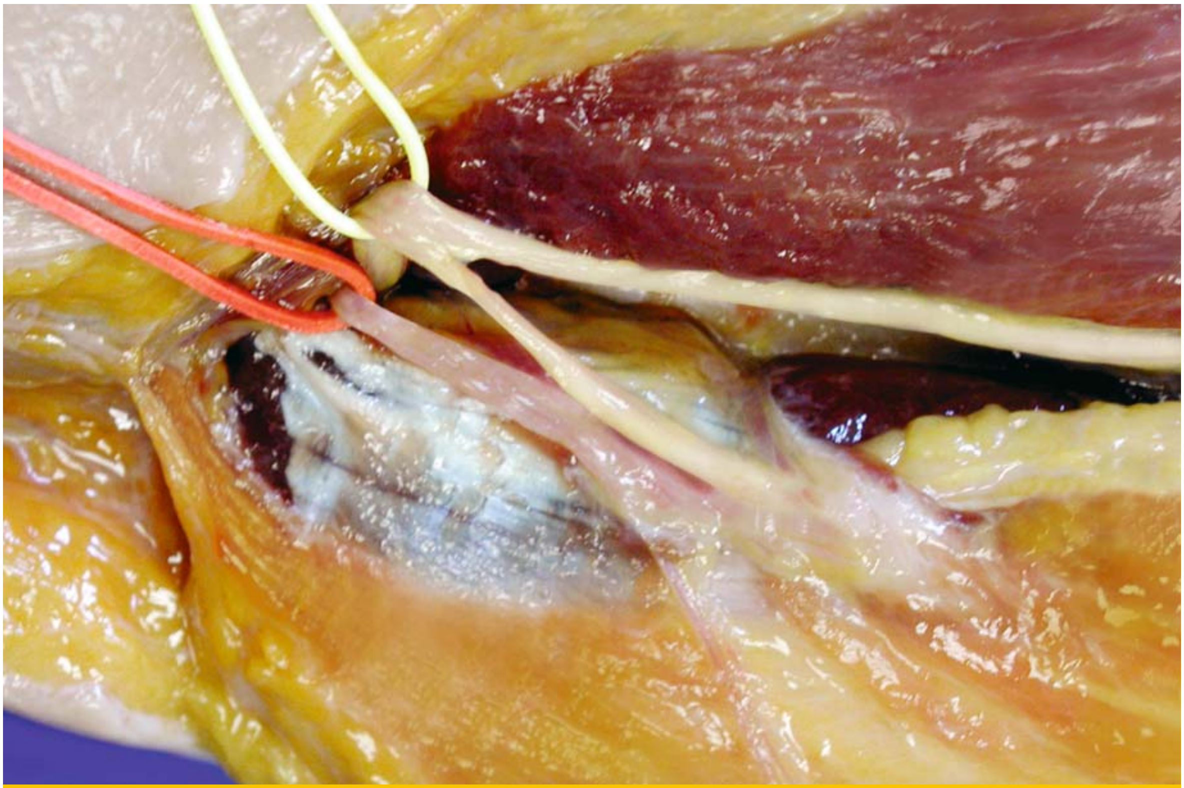
Step 7 • Detachment of septum from humerus bone



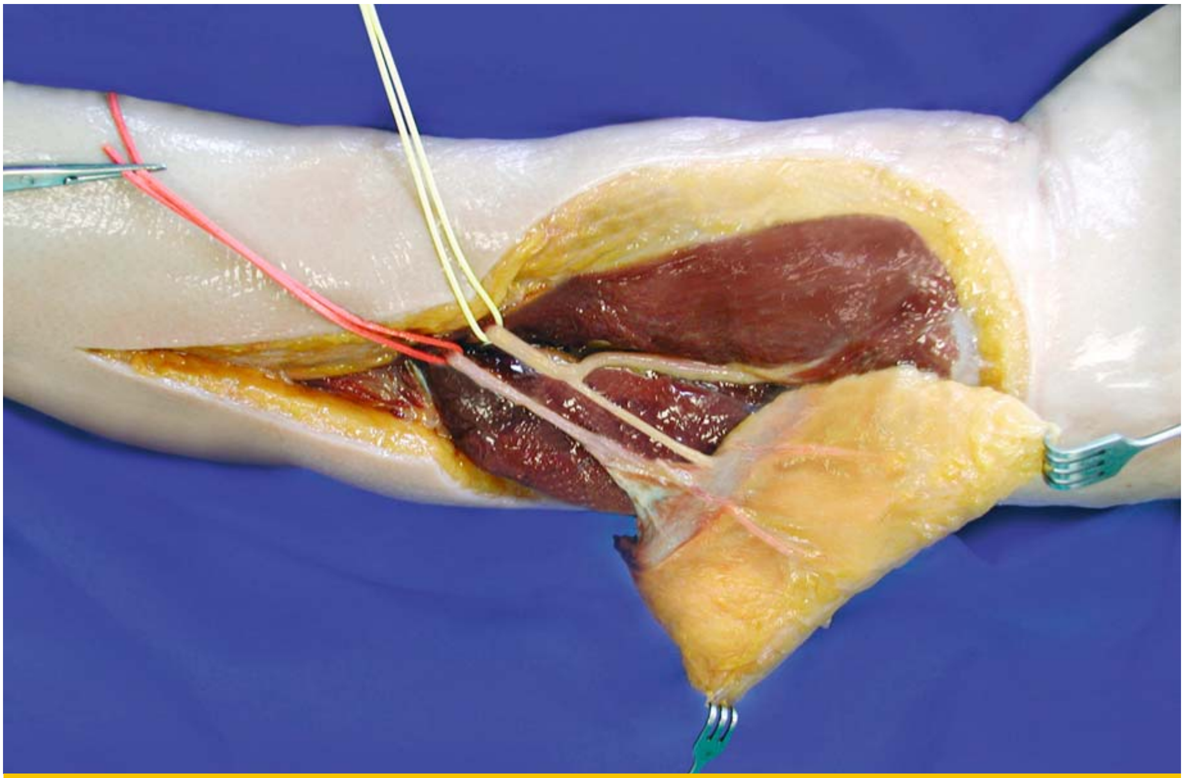
Cross section anatomy of the right arm, epiperiosteal detachment of lateral intermuscular septum



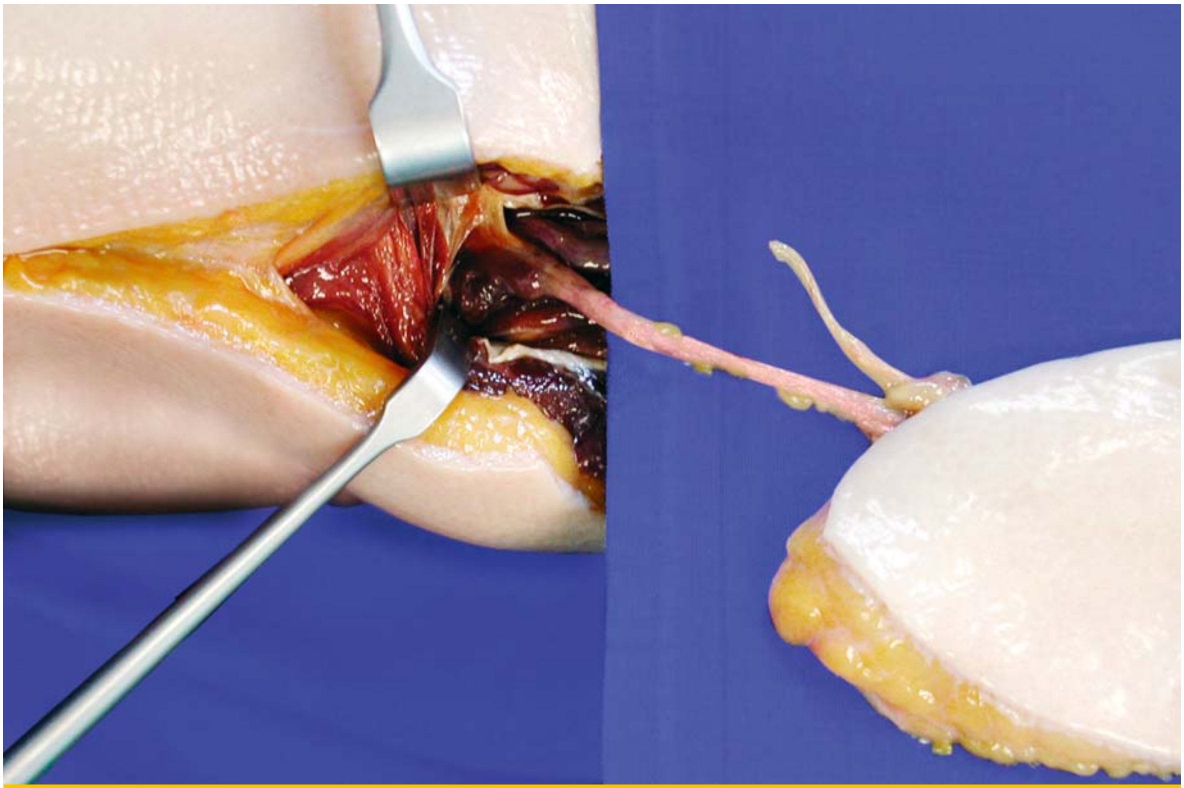
Step 8 • Identification of PCNA and flap hilum by following the radial nerve



Step 9 • Separating the PCNA, branching off from the radial nerve and PRCA



Step 10 • Further exposure of the pedicle



Step 11 • Completion of flap raising by transection of PCNA

Comments

Planning

The muscle groove between the brachial muscle and the biceps muscle of the arm might be mistaken for the lateral intermuscular septum, so the position of the brachial muscle is controlled by palpation. The skin island should not be too narrow, because then the intermuscular septum can easily be missed.

Steps 1–3: The intermuscular septum should not be injured by undermining of the skin paddle. The incision down to the fascia should be performed perpendicularly through the fatty tissue. The fascia should be incised until the muscle fibers are clearly visible.

Step 2: The intermuscular septum can easily be injured following sharp instead of blunt dissection.

Step 6: The septum must be detached from the bone at the level of the periosteum. The correct plane of dissection is controlled by direct palpation of the humerus bone.

Step 7: The vascular pedicle might be missed if the septum is not incised directly at the humerus, so the scissors should be kept in direct contact with the periosteum while transecting the septum.

Steps 9, 10: The vascular pedicle can easily be injured as it enters the flap at its cranial pole. The pedicle should thus be separated from the radial nerve carefully and a loop placed around the vessels before the cranial pole of the flap is completely circumcised.

Chapter 3

Anterolateral Thigh/ Vastus Lateralis Flap

Development and Indications

In 1984, Song and coworkers described the thigh as a donor site for three new flaps, which they raised from its posterior, anteromedial, and anterolateral aspect [241]. Of these three flaps, the anterolateral thigh flap became most popular, especially in head and neck reconstruction. Although originally described as a fasciocutaneous flap nourished by a septocutaneous perforator of the descending branch of the lateral circumflex femoral artery, the design of the flap significantly depends on the course and location of the cutaneous vessels, the anatomy of which can vary considerably. Because of the fact that the perforator often runs through the vastus lateralis muscle instead of strictly along the intermuscular septum, parts of the vastus lateralis muscle have to be included in the flap in these cases. Besides the possibility of raising large skin paddles on a single perforating vessel, the vastus lateralis muscle can be transferred as a muscle-only flap, being safely perfused by the descending branch. Thus, there is a number of flap-raising possibilities at the anterolateral thigh, offering a wide spectrum of flaps to be harvested. In one of the first large clinical series, Zhou et al. described successful transplantation of this flap in 32 patients, most of them having defects in the region of the face and scalp [300]. Based on a single perforator, a flap design was described reaching in length from the distal end of the tensor fasciae latae muscle to a level 7 cm above the patella and in width from the medial edge of the rectus femoris muscle to the lateral border of the vastus lateralis muscle. According to Koshima and coworkers, who reported on 22 reconstructions of head and neck defects, the flap can be up to 25 cm long and 18 cm wide [135]. Two years later, the same author combined the anterolateral thigh flap with neighboring skin, myocutaneous, and bone flaps using the lateral circumflex femoral system to treat massive composite defects of the head and neck, performing an additional anastomosis at the distal end of the descending branch [136]. In 1995, the usefulness of the anterolateral thigh flap to cover defects in the lower extremity was demonstrated by Pribaz and coworkers, especially because of the possibility to harvest and transfer the flap using epidural anesthesia [192]. An important variation of designing the anterolateral thigh flap was introduced by Kimura et al. in 1996, who performed a primary radical thinning procedure, only leaving a small cuff of fatty tissue around the perforator [131]. With this procedure, ultrathin flaps were created, which are very useful to cover superficial skin defects [34, 131, 279, 294]. To improve intraoral defect cover, Wolff et al. performed additionally de-epithelialization of the thinned flaps to create a mucosalike flap surface [290]. In the years to follow, the exceptionally wide spectrum of indications and the high reliability of the flap have been reported, especially by authors from Asian countries. In 2002, Wei et al. published a series of 672 anterolateral thigh flaps with a total flap failure in only 12 patients [279]. An even larger number of 1,284 patients was presented by Gedebou and Wei in the same year, who described the anterolateral thigh flap as one of the most useful soft-tissue flaps, especially in head and neck reconstruction [79].

The vastus lateralis muscle first was used as a pedicled regional flap to treat trochanteric pressure sores [28, 63, 100, 175] and to repair defects in the gluteal region [120] and knee [251]. In 1987, Drimmer and Krasna described myocutaneous vastus lateralis flaps in four patients to treat decubiti in the gluteal region [64]; later, Rojviroy et al. used this pedicled myocutaneous flap to cover trochanteric pressure sores in paraplegic patients [205]. The first microsurgical transfer of the vastus lateralis muscle flap to the oral cavity was reported by Wolff in 1992 [281], who covered intraoral defects using myofascial and myocutaneous flaps. In further clinical series, the same author described the usefulness of the muscle in combination with one or more skin paddles for reconstruction in the head and neck, including the skull base and perforating defects of the cheek [282, 284, 289, 290]. Because muscle flap raising can be carried out independently from cutaneous vessels, flat and fascial covered flaps can be created from the distal half of the vastus lateralis, giving the possibility to obtain vascular pedicles of up to 15 cm.

Anatomy

The vastus lateralis represents the largest portion of the quadriceps femoris muscle and is localized between the vastus intermedius, biceps, and rectus femoris muscle. Its origin is from the intertrochanteric line, the greater trochanter, gluteal tuberosity, and the lateral intermuscular septum. Together with the other muscles of the quadriceps group, its tendon builds the patellar ligament and thus is a strong extensor of the leg [206, 280]. Along with the gluteus maximus muscle, the vastus lateralis forms the "vastogluteal muscle sling," leading to extension, external rotation, and adduction of the leg [144]. The muscle, which has a dimension of about 10 × 25 cm, is innervated by a motor branch of the femoral nerve. This nerve enters the muscle at its medial border in the proximal and intermedial segments and follows the course of the main dominant vascular pedicle. The vascular supply of the vastus lateralis muscle comes from the descending branch of the lateral circumflex femoral artery and its two venae comitantes, having a diameter of 1.5–2.5 mm (artery) and 1.8–3.3 mm (veins) [281]. According to Mathes and Nahai, the muscle has a type I pattern of circulation, providing perfusion of the whole muscle from this dominant vascular pedicle [162, 163]. Additional minor pedicles reach the muscle proximally (transverse branch of the lateral circumflex femoral artery) and distally (lateral superior genicular artery), but they have no significance for microvascular transfer. After taking off from the lateral circumflex femoral artery, the descending branch reaches the medial rim of the vastus lateralis muscle in its proximal segment and courses distally to communicate with the superior genicular artery. Because the whole muscle is nourished by side branches of the artery, muscle flaps can be raised from each portion of the vastus lateralis. The vascular pedicle can easily be exposed in the triangle built by the tensor fasciae latae, vastus lateralis, and rectus femoris muscle in the proximal third of the thigh. Here, the pedicle has a length of 6–8 cm before entering the vastus lateralis muscle. When used as a rotation flap, the proximally based muscle can reach the trochanteric, gluteal, perineal, and lower abdominal region. As a distally based flap, the lower third of the muscle, which is supplied by the distal minor pedicle, can be used for defect cover around the knee [251].

In addition to supplying blood to the vastus lateralis muscle, the descending branch gives off myo- or septocutaneous branches, providing the anatomical basis of the myocutaneous vastus lateralis- or septocutaneous anterolateral thigh flap. These flaps, which can be considered as one entity, only differ by the amount of muscle tissue included during flap raising. Depending on the course of the cutaneous vessels, a portion of the medial edge of the vastus lateralis muscle must be removed, forming a protecting cuff around myocutaneously running vessels. Anatomical investigations have shown that the dominant cutaneous vessel of the anterolateral thigh has a myocutaneous course in 80–90 %. However, since the myocutaneous vessel traverses the muscle close to its medial edge, a small cuff of muscle must be included, but the function of the vastus lateralis can be preserved completely. For extended and deep defects, larger portions of the vastus lateralis muscle of the same size as the skin paddle can be harvested to create voluminous myocutaneous flaps. In only 10–20 % the dominant cutaneous vessel does have a direct course to the skin, running along the lateral intermuscular septum between the rectus femoris and vastus lateralis muscles and piercing the fascia lata without traversing through the vastus lateralis muscle. These anterolateral thigh flaps are raised without any muscle tissue and thus are thin, pliable skin paddles that are well suited for reconstructions in the head and neck area, including the oral cavity.

In a number of anatomical investigations and clinical series, the vascular anatomy of the anterolateral thigh has been found to be variable, making it always necessary first to expose the cutaneous vessel before the location of the skin paddle can be determined definitively. The dominant cutaneous vessel can be found within a 4 cm radius at the midpoint of a line between the anterior superior iliac spine and the lateral border of the patella in nearly all cases [162, 281]. To facilitate exposure of the cutaneous perforator, preoperative mapping using an audible Doppler is generally recommended. Although the definite course of this dominant cutaneous vessel can only be explored during flap raising, a myocutaneous pattern can be expected if the Doppler signal is detected not directly over the palpable groove between the rectus and vastus lateralis muscle, but 2–4 cm lateral to the septum above the medial portion of the muscle. Once the exact location of the perforator is defined, the skin paddle can be outlined over the middle third of the lateral thigh between the medial border of the rectus femoris and the lateral border of the vastus lateralis muscle, having a dimension of up to 12 × 30 cm [162]. Depending on the exact location of the main cutaneous perforator, the length of the vascular pedicle varies with an average of 12 cm [235]. In addition to this main perforator, the descending branch gives off 1–3 additional cutaneous branches that reach the skin more distally to the main perforator. Although the most distally located of these additional vessels are not reliable for skin perfusion, a second perforator can be found in about 90 % of all cases 4–9 cm distal to the main perforator, making it possible to build a second independent skin paddle. Like the dominant perforator, this additional cutaneous vessel has a myocutaneous course in 80–90 %, piercing the muscle at a distance of 2–5 cm from its medial rim. The variations of the course of the cutaneous perforators were described in detail by Sieh, who found vertical musculocutaneous perforators in 57 % and horizontal myocutaneous perforators in 27 %, whereas vertical septocutaneous perforators were only found in 11 % and horizontal septocutaneous perforators in 5 % of all of their 36 clinical cases [235]. The length of the cutaneous perforating vessels varied between 3.6 and 7.7 cm.

The vascular anatomy of the cutaneous perforators of the lateral thigh was found to be a suitable basis for primary flap-thinning procedures, which were first described by Kimura and Satoh in 1996 [131]. In their first five cases, they removed the subcutaneous fatty tissue uniformly from the whole flap except for the region around the perforator, obtaining a flap thickness of only 3–4 mm.

Further experience with primary thinning has shown that the radical removal of fatty tissue does not impair flap perfusion if the subdermal vascular plexus is preserved and attention is paid to the vascular territory of the corresponding flap vessels [2, 137]. Although Ross and coworkers had a higher complication rate in their clinical series [207] and Alkureishi et al. experimentally demonstrated reduced dye perfusion of the thinned flaps [3], in general the literature reports low complication rates [3, 137, 279, 290]. All authors agree, however, that a high degree of technical skill and exact knowledge of the vascular anatomy are necessary to perform flap thinning. A prerequisite for successful thinning is the preservation of the subdermal vascular plexus, which means that the minimal flap thickness should not be less than 3–4 mm. Under these conditions, the size of the vascular territory of a thinned flap corresponds to conventional flaps [137, 182, 279]. Kimura et al. (1996) maintain that the vessel anatomy of the anterolateral thigh flap is especially suitable for flap thinning [131] if the perforator courses directly to the skin. To obtain thinned flaps, other authors perform additional dissection through the vastus lateralis muscle if the perforator courses myocutaneously [29, 79, 279, 290]. Using this technique, it is possible to raise voluminous, extensive flaps, as well as very thin, small flaps from the same donor region.

Advantages and Disadvantages

Since its first description by Song in 1984 [241], the anterolateral thigh has developed into one of the most preferred donor sites for soft-tissue reconstruction, especially in the head and neck area. With a failure rate of less than 2 %, Wei and coworkers performed reconstruction in 660 cases, most of them having defects in the head and neck region. Irrespective of whether the skin vessels were septo- or myocutaneous, they raised versatile soft-tissue flaps in which the thickness and volume could be adjusted for the extent of the defect [279]. Based on their experience, the anterolateral thigh could replace most of the other donor sites for soft-tissue free flaps. Besides the immense experience of Wei's group, similar results have been reported by a number of other authors, who have described success rates of about 95 % with a wide indicational spectrum, reaching from perforator-based ultrathin skin flaps to myocutaneous vastus lateralis and extensive chimeric flaps, which include parts of the surrounding muscles and even segments of the iliac crest [136]. The donor site can be closed primarily if the width of the flap does not exceed about 8 cm, and there are no significant functional or aesthetic impairments in the lower leg even after harvesting a large portion of the vastus lateralis muscle.

However, when raising flaps from the anterolateral thigh, the surgeon must be aware of possible variations in vascular anatomy. Besides the variability of the course and location of the main cutaneous perforator, the absence of cutaneous branches is possible in rare cases [135, 140, 279, 289] and has been reported to occur in up to 5.4% [128]. Although the branching pattern of the skin vessels in a series of 74 clinical cases could be classified into eight categories, no variation was found, making flap raising impossible [128]. In this series, 2.3 perforators per case were found, 82% of them having a myocutaneous course, branching off at different levels from the descending branch, or circumflex femoral artery, the transverse branch, or directly from the profunda femoris artery [7, 128]. Because the veins that accompany the nutrient artery can show different backflow strength, venous return should be checked before anastomosis. In a clinical study of 115 flap-raising procedures at the anterolateral thigh, the descending branch was found to be absent in 22.6 %, being replaced by the medial descending branch or other strong muscle branches [7]. Although in this study the anatomical course of the descending branch could be classified into six different categories, flap elevation was possible in all cases, because at least one cutaneous perforator was observed regularly.

For intraoral defect cover, the thickness of the flap can be disadvantageous, especially in myocutaneous flaps carrying a large portion of muscle tissue. In these cases, muscle or fatty tissue must be primarily removed without injuring the cutaneous vessel, but these thinning procedures should only be carried out by experienced surgeons who have an exact knowledge of the vascular anatomy. Because of neurogenic muscle atrophy and secondary shrinkage, purely muscular flaps only have a limited indication for intraoral soft-tissue replacement [285]. For primary wound closure, the width of the skin paddle is limited to about 8–9 cm. In males sometimes heavy hair growth can be observed on the lateral thigh. Apart from some loss of sensation, donor-site morbidity is low, but can increase when wider flaps needing a split-thickness skin graft for closure of the donor site or flaps including significant parts of the vastus lateralis muscle have been harvested [129].

Flap Raising

Preoperative Management

Despite the anatomical variations described for the vascular pedicle of the anterolateral thigh/vastus lateralis flap, angiography is not helpful in locating the variable positions of the septo- or myocutaneous branches of the descending branch. Preoperative evaluation of the perforators should be performed using a Doppler probe by auscultating the skin in the region of the lateral intermuscular septum and over the medial parts of the vastus lateralis muscle.

Patient Positioning

The patient is placed in a supine position, and the whole leg is included in the operating field to allow for free positioning of the extremity and for modifying the flap design, if necessary. Circular disinfection is performed from the hip down to the lower leg.

Flap Design

The standard skin paddle of the flap may be extended from the rectus femoris to the lateral border of the vastus lateralis muscle, covering the middle third of the thigh. The center of the flap depends on the individual location of the perforator(s), which can be found a few centimeters proximal to the midpoint of the interconnection between the anterior superior iliac spine and the patella in most patients. Because of the variability of the perforators, the skin paddle is not circumcised until the perforator is identified from the medial border of the flap. The incision to expose the vascular pedicle is marked between the tensor and rectus femoris muscle at the proximal thigh.

Flap Raising

Step 1

The incision is made over the rectus femoris muscle, keeping a distance of 2–3 cm from the lateral intermuscular septum, which can be palpated between the rectus and vastus lateralis muscle. The location of the septum is represented by the interconnecting line between the anterior superior iliac spine and the lateral border of the patella. Cranially, the incision is extended along the palpable groove between the rectus femoris and tensor muscle for exposure of the vascular pedicle. The fascia lata still remains intact. Again, it should be mentioned that before the skin paddle is outlined, the perforator(s) must be visualized in the subfascial plane to determine the center of the flap.

The fascia is incised along the rectus femoris muscle so that the intermuscular septum is completely included in the flap. To gain optimal access to the pedicle, the proximal incision is placed along the groove between the tensor and the rectus muscle.

Step 2

The rectus femoris and tensor muscle are bluntly separated from each other, and by retracting the rectus femoris muscle medially, the vascular pedicle becomes visible. At the middle third of the thigh where the skin perforators are to be expected, the intermuscular septum is left intact.

Step 3

A vessel loop is placed around the pedicle, and the intermuscular septum is opened with scissors directly at the lateral rim of the rectus muscle. Great care must be taken not to transect perforating vessels arising from the descending branch into the septum. The use of magnifying glasses is recommended to make identification of the perforators easier.

Step 4

It can clearly be seen that the pedicle consists of one artery that is the descending branch, two concomitant veins, and a motor branch of the femoral nerve, innervating the vastus lateralis muscle. The pedicle runs distally underneath the anterior border of the vastus lateralis muscle to anastomose with the vascular network around the knee.

Step 5

If no septocutaneous perforators are found, myocutaneous perforators will be present that pierce the vastus muscle along its anterior border. This is the case in the majority of patients. Using magnifying glasses, these myocutaneous perforators become visible entering the muscle along its undersurface at the anterior muscle rim. Because the perforators traverse the muscle closely underneath its surface, their pulsation can often be observed, and the tiny vessels can be followed to the skin paddle. In this cadaver, two myocutaneous perforators are seen penetrating the vastus lateralis muscle at its anterior border and entering the skin paddle, which now can be designed definitively. Distally, the vascular pedicle is exposed above the intermedius fascia and then ligated.

Step 6

After identification of the perforators, the skin island is circumcised completely, including the deep fascia, and fixed at the anterior border of the muscle to prevent shearing the perforators. Again, it must be emphasized that definite determination of the flap margins is only possible after the perforators have been visualized.

Step 7

By retracting the rectus femoris muscle, the vascular pedicle is followed distally and exposed on the surface of the vastus intermedius muscle. With careful elevation of the anterior rim of the vastus lateralis, a number of vascular branches become visible, reaching the muscle and skin paddle.

Step 8

Step 9

Although the myocutaneous perforators travel through the muscle for only a few centimeters, a large segment of the vastus muscle is integrated in the flap to safely include all perforating branches. Starting distally, the muscle is dissected in the plane above the intermedius fascia until the anterior rim of the vastus lateralis is nearly reached. Additional muscle branches will be transected during dissection of the muscle segment, which then have to be cauterized or clipped.

Step 10

The neurovascular pedicle is now dissected proximally, carefully leaving the fascia intact that forms the intermuscular septum and contains the perforating vessels. Further muscular branches to the vastus intermedius muscle must be ligated; these are mostly found in the proximal part of the pedicle.

Step 11

Flap raising is finished by further dissection of the vascular pedicle in the proximal direction until the lateral circumflex femoral artery is reached. At the cranial pole of the flap, residual fibers of the vastus lateralis muscle are transected, to free the myocutaneous paddle completely.

Step 12

The components of the neurovascular pedicle are bluntly separated from each other, and the flap is now ready for microvascular transplantation. It can be seen that the flap vessels branch off from the lateral circumflex femoral artery. Direct closure is possible if the width of the skin paddle does not exceed 8–9 cm. Burow's triangles must be excised at the cranial and caudal incision to prevent "dog-ear" formation following linear closure.

Myofascial Flap

Step 13

For raising of a muscle-only flap, skin, subcutaneous tissue, and fascia are incised along the intermuscular septum, which is palpated between the rectus and vastus lateralis muscle.

Step 14

After subfascial exposure of the vastus lateralis muscle, dissection of the pedicle is performed proximally, elevating and retracting the rectus femoris muscle. A vessel loop is placed around the descending branch and concomitant veins.

Step 15

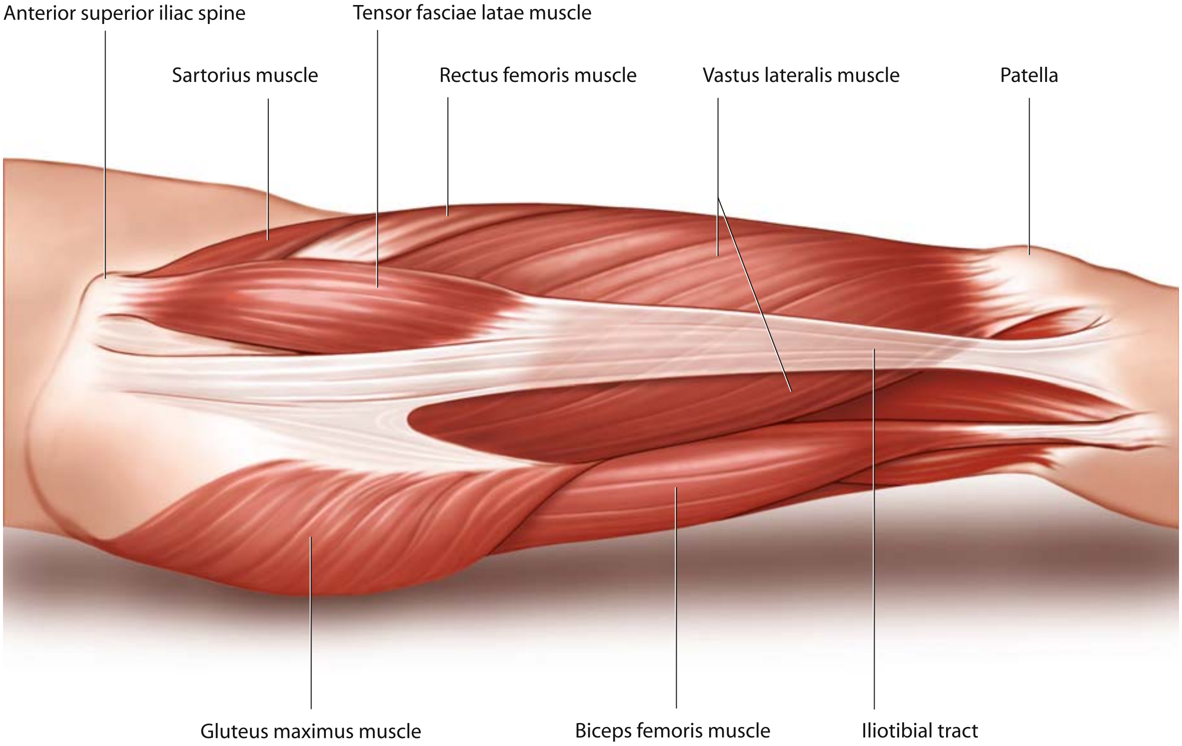
The vessels now can easily be followed to the distal parts of the muscle where a myofascial flap is outlined. Because no care must be taken on the perforating vessels, the flap design is variable, but it may not exceed the borders of the vastus lateralis muscle. Nevertheless, before raising the flap, the vascular branches to the segment of muscle intended to be elevated must be clearly identified.

Step 16

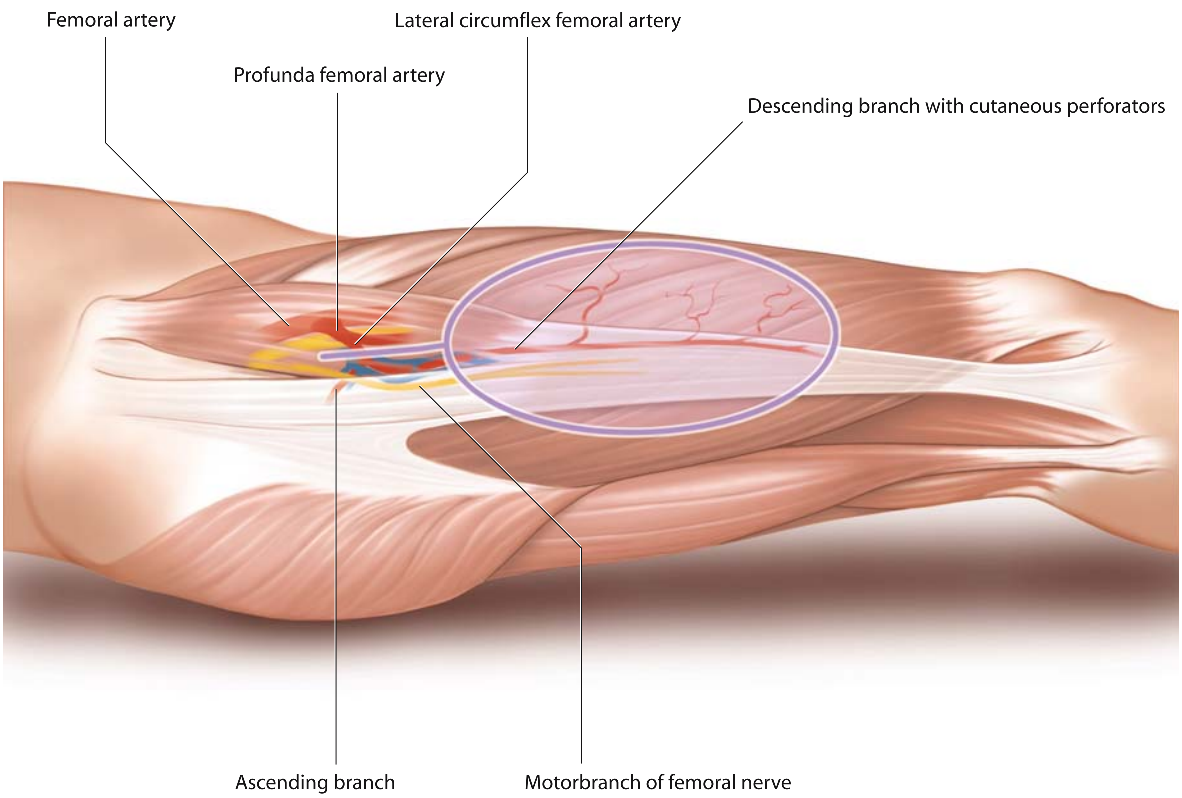
A number of side branches reach the vastus muscle from the dominant pedicle, demonstrating that almost the entire muscle can be transferred on the descending branch.

Elevating the muscle segment at the transition of the medial to the distal third of the vastus lateralis permits a long vascular pedicle to be obtained, which makes this flap useful for coverage of skull-base defects. Like the myocutaneous flap, a suction drain is inserted underneath the rectus muscle and the skin is closed in layers. No immobilization of the patient is necessary.

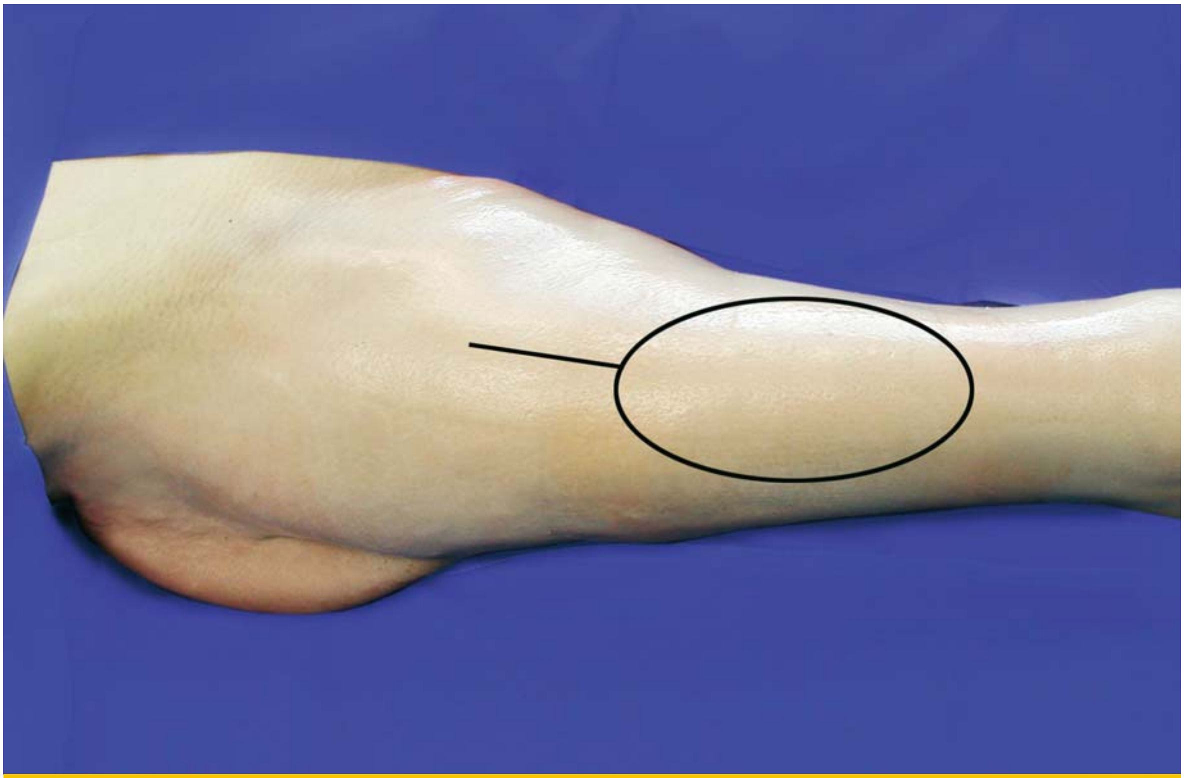
Step 17



Muscles of the anterolateral thigh



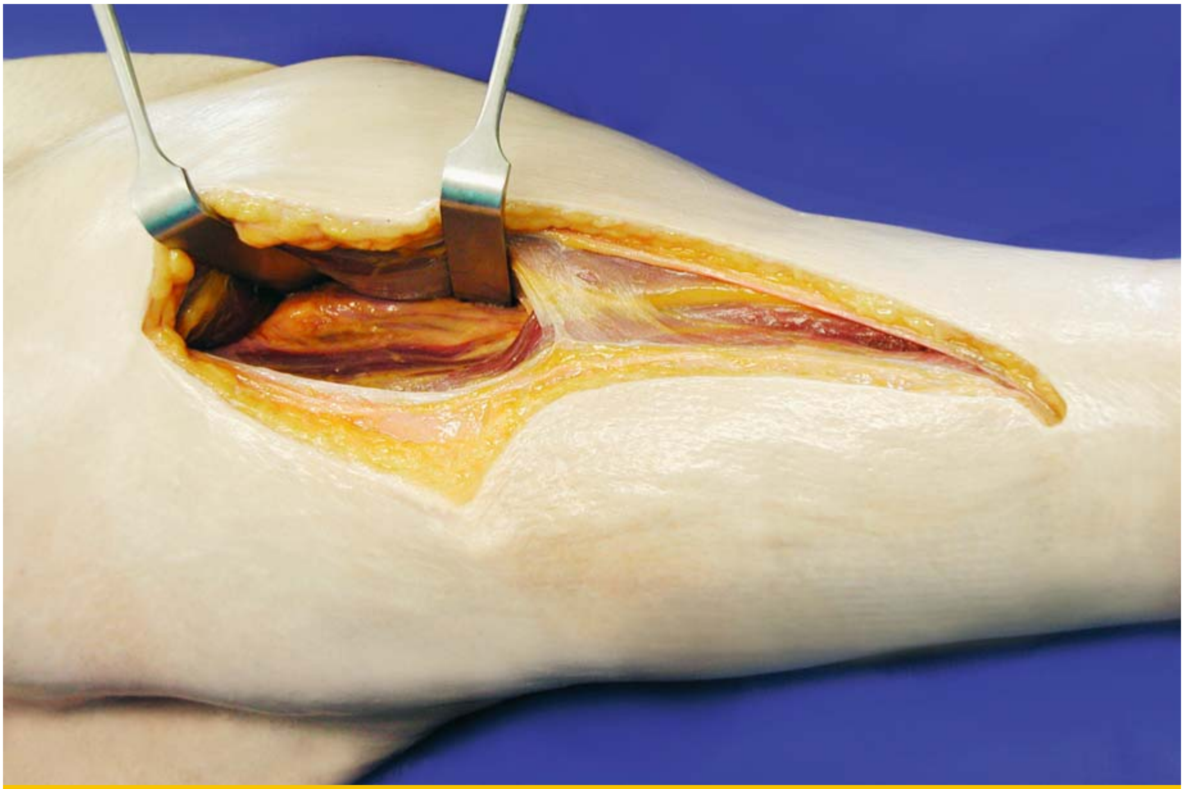
Vascular system of the anterolateral thigh and standard skin paddle



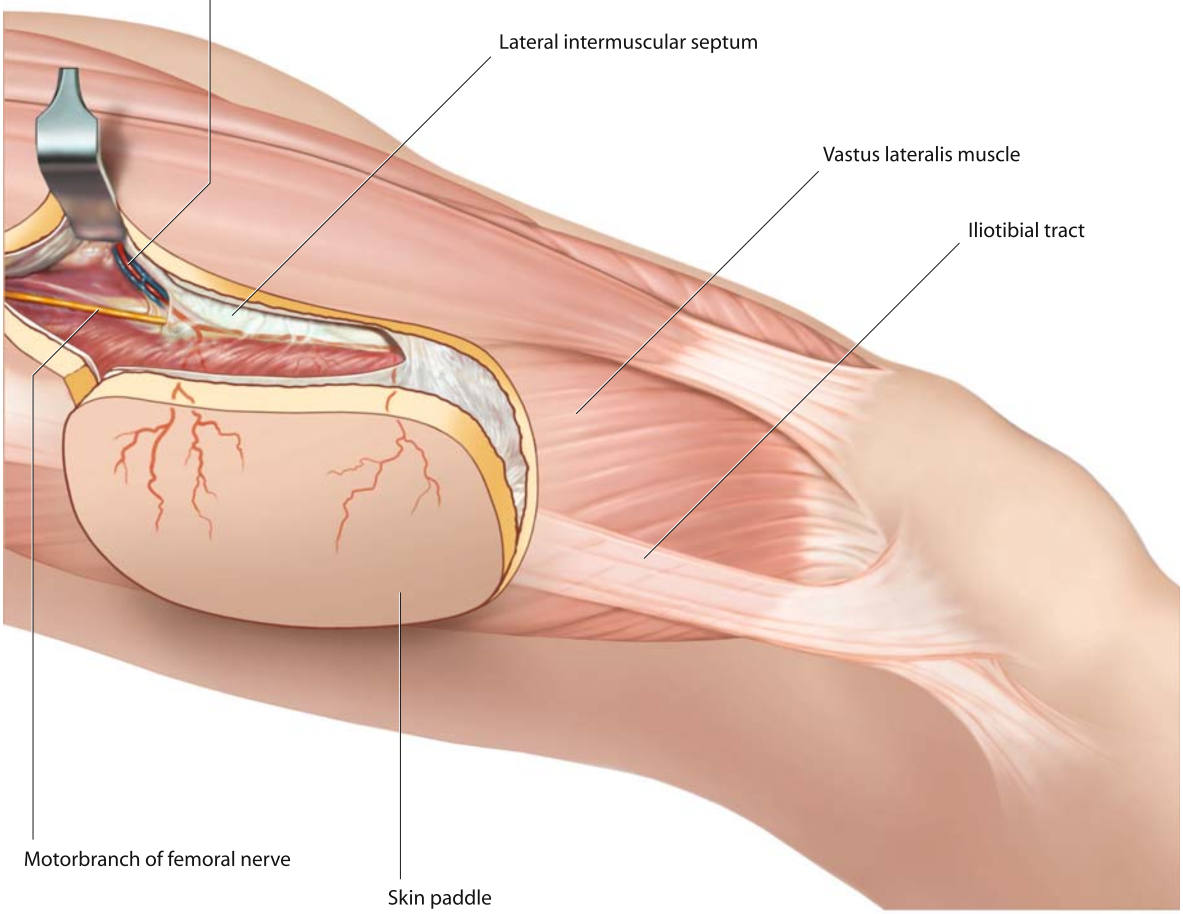
Standard flap design

Step 1 • Skin incision

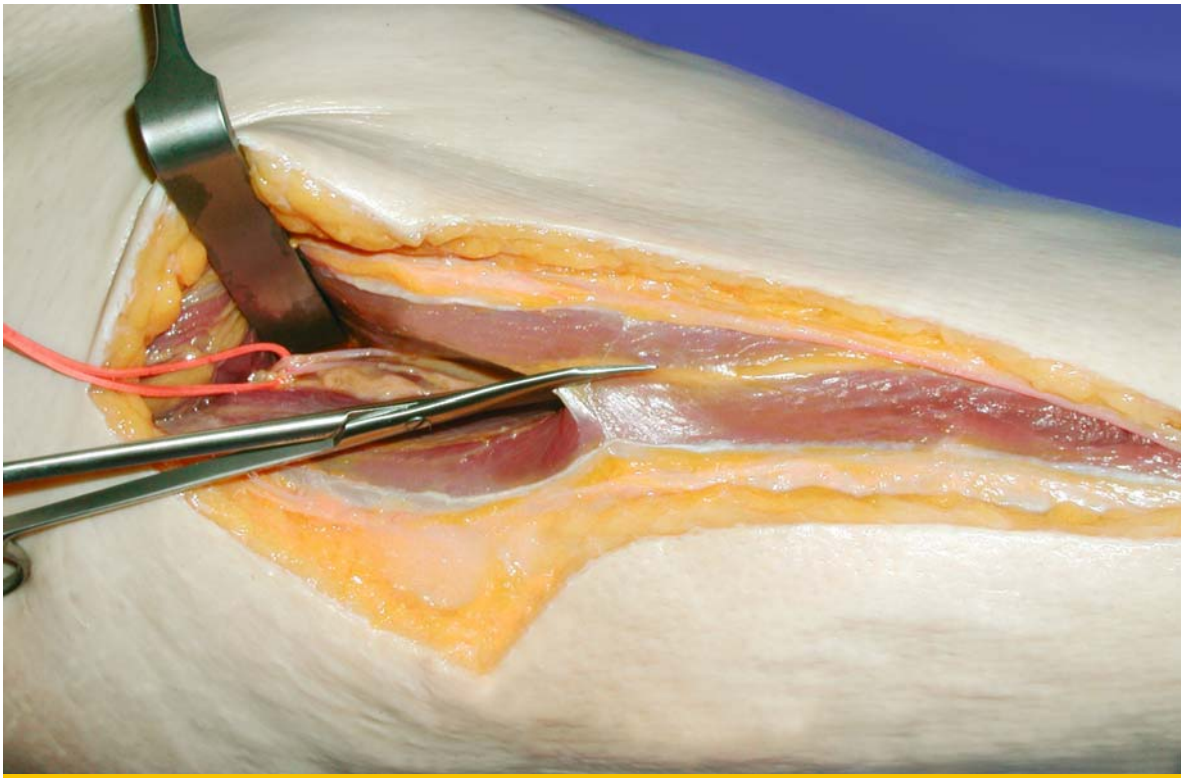
Step 2 • Incision of fascia



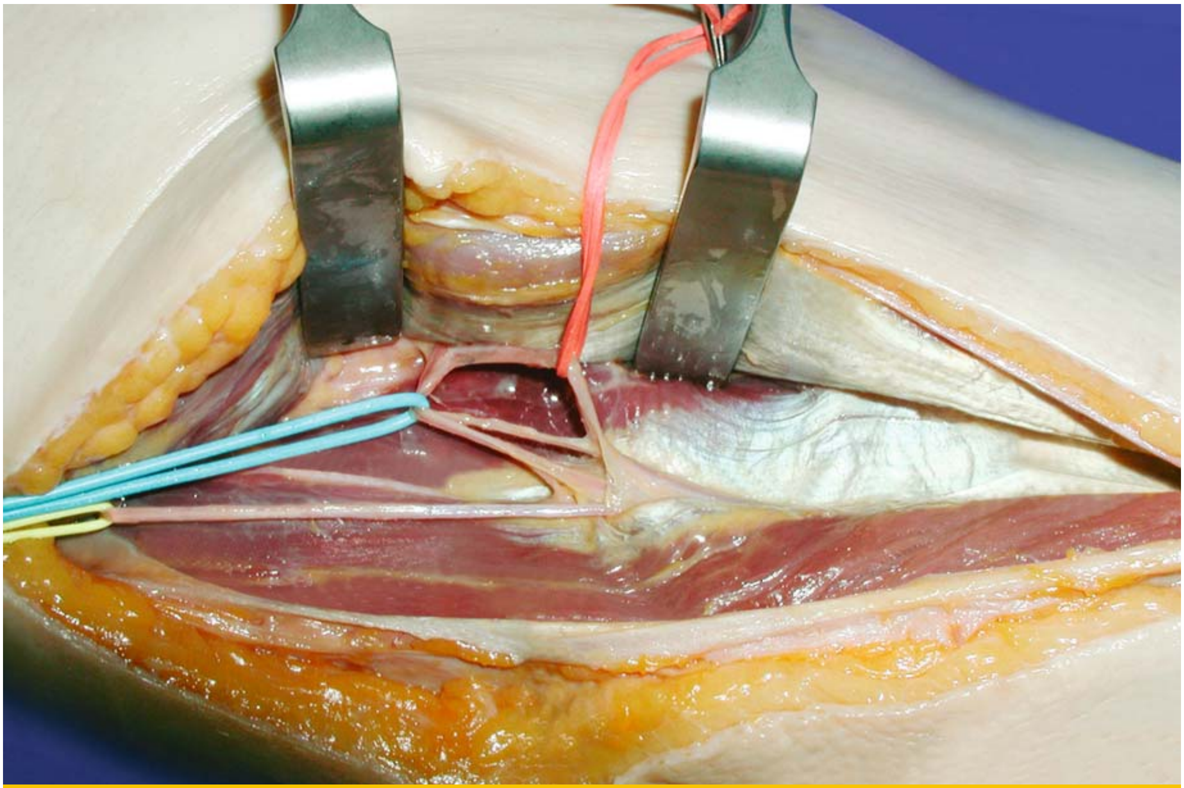
Step 3 • Exposure of vascular pedicle



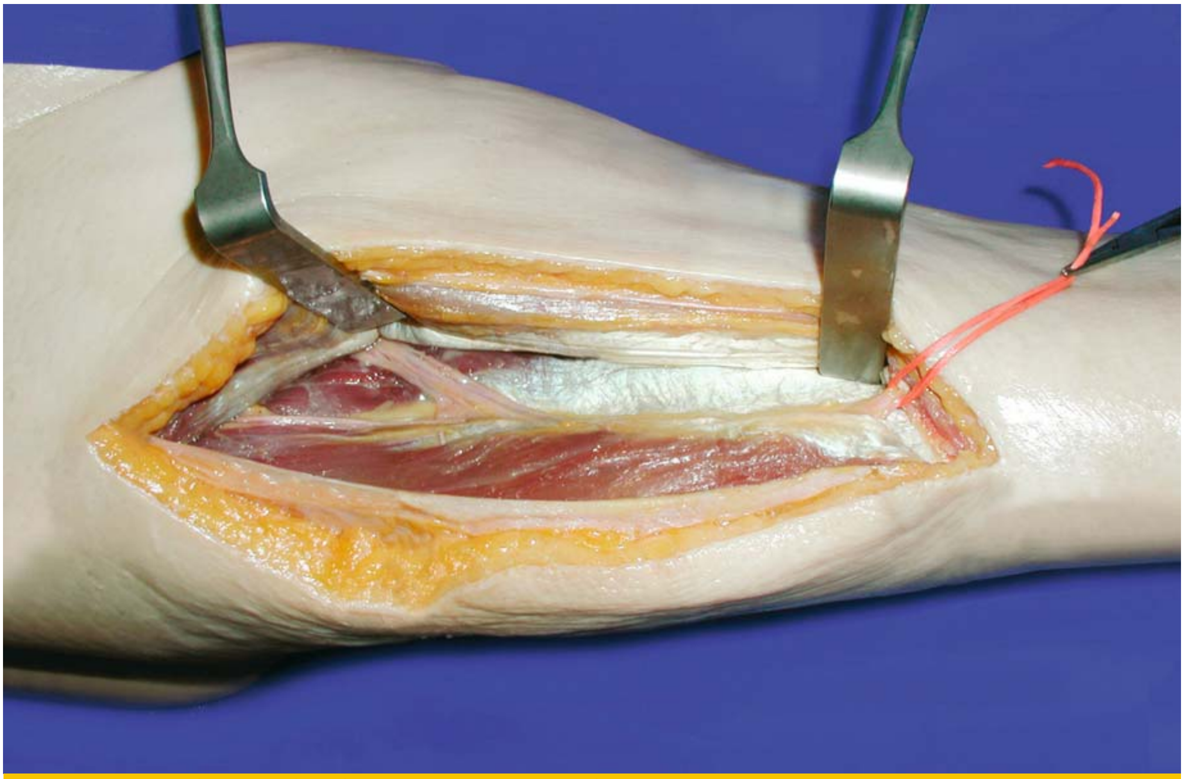
Anatomy of the lateral intermuscular septum and course of perforators



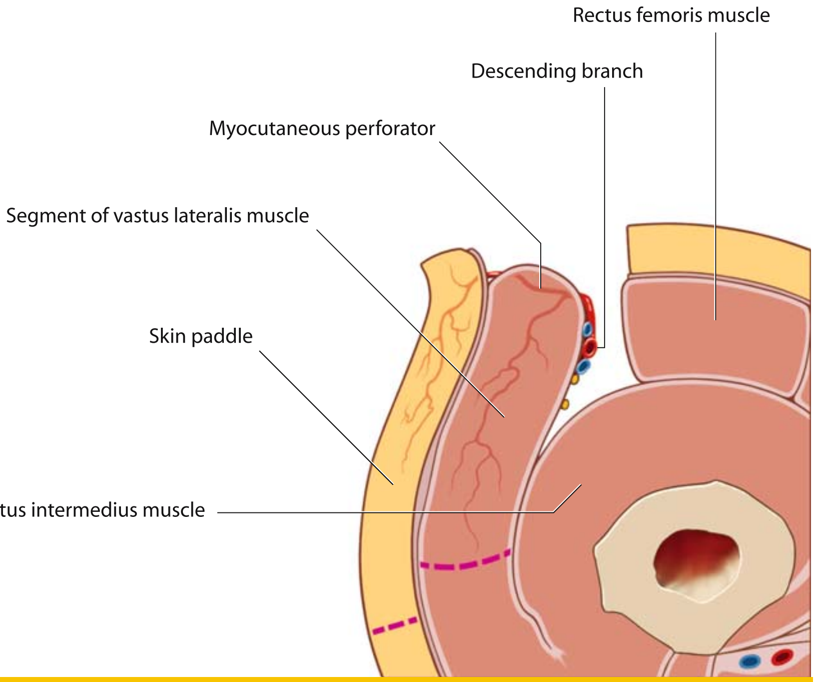
Step 4 • Detachment of lateral intermuscular septum from rectus femoris muscle



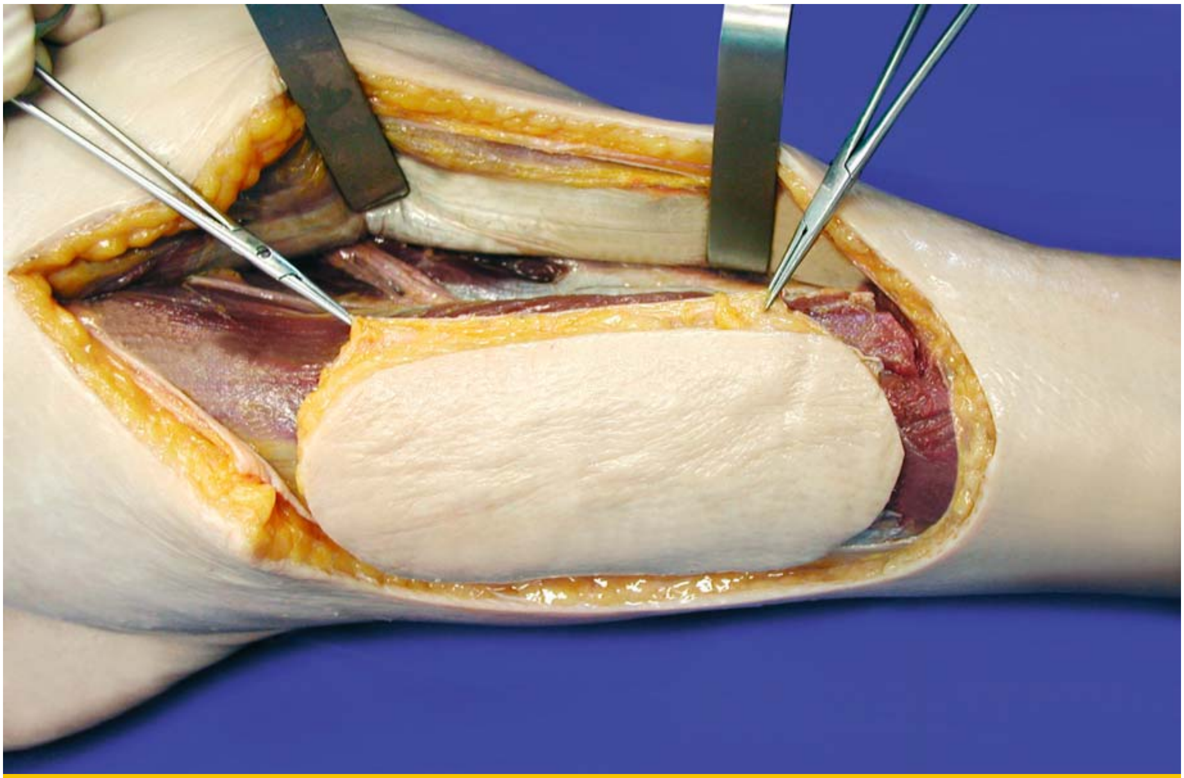
Step 5 • Separation of descending branch from concomitant veins and nerve



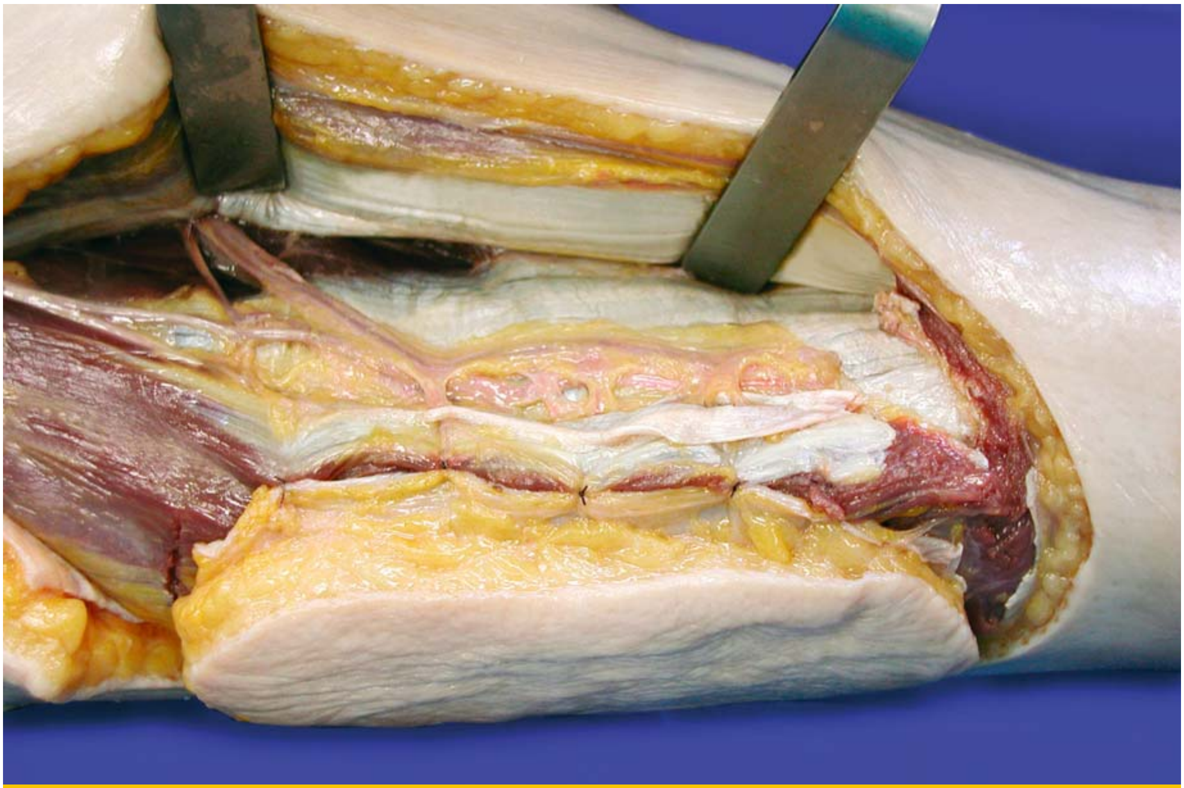
Step 6 • Identification of perforators, distal ligation of pedicle



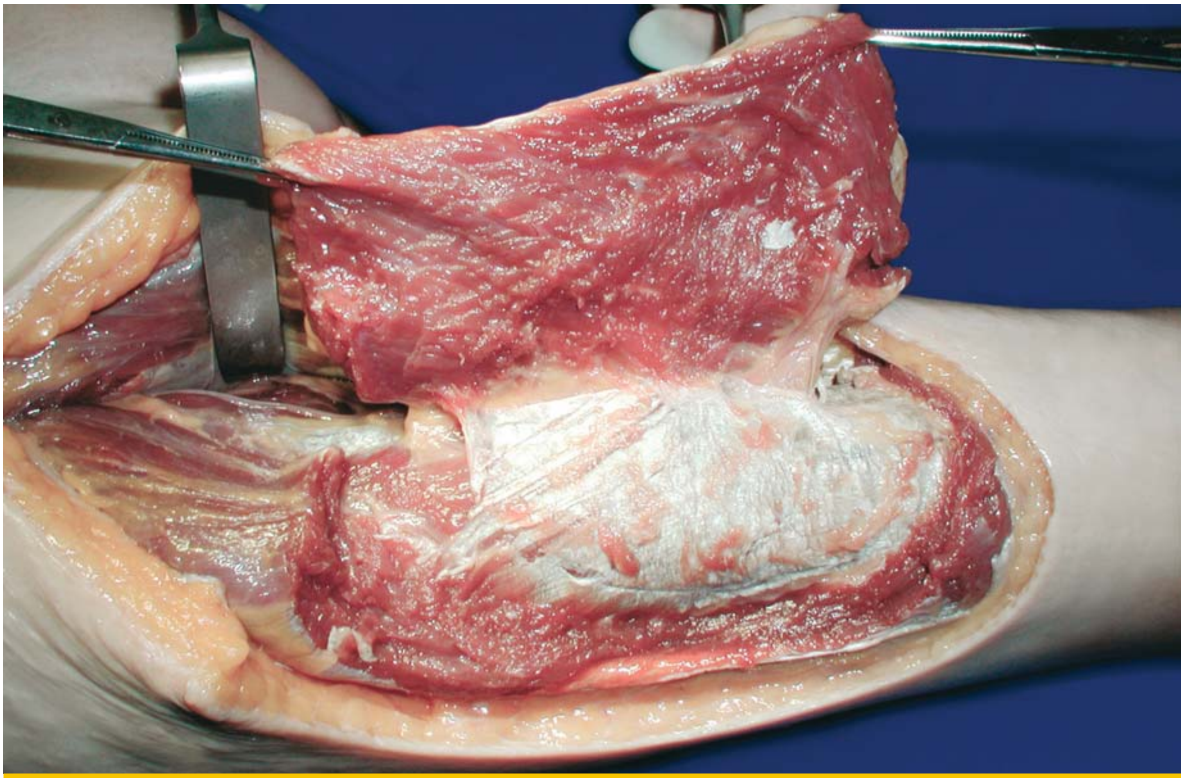
Course of myocutaneous perforator



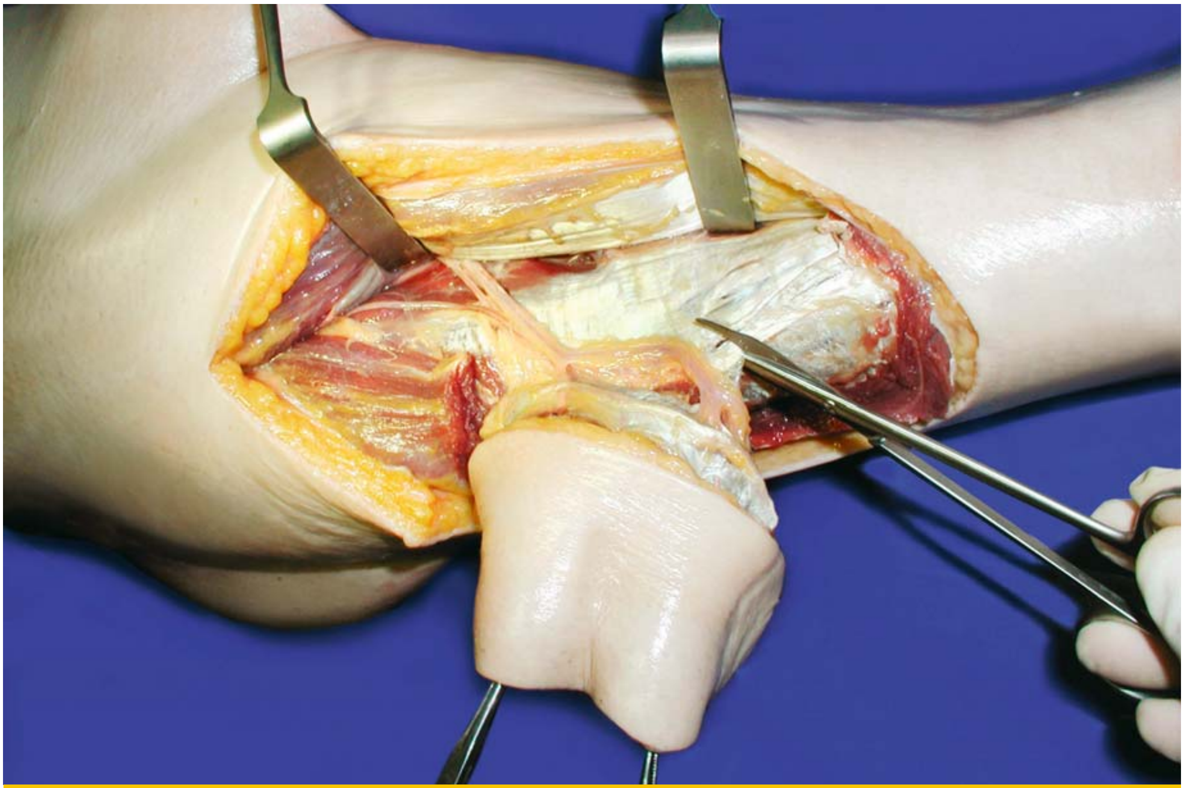
Step 7 • Circumcision of skin paddle including fascia



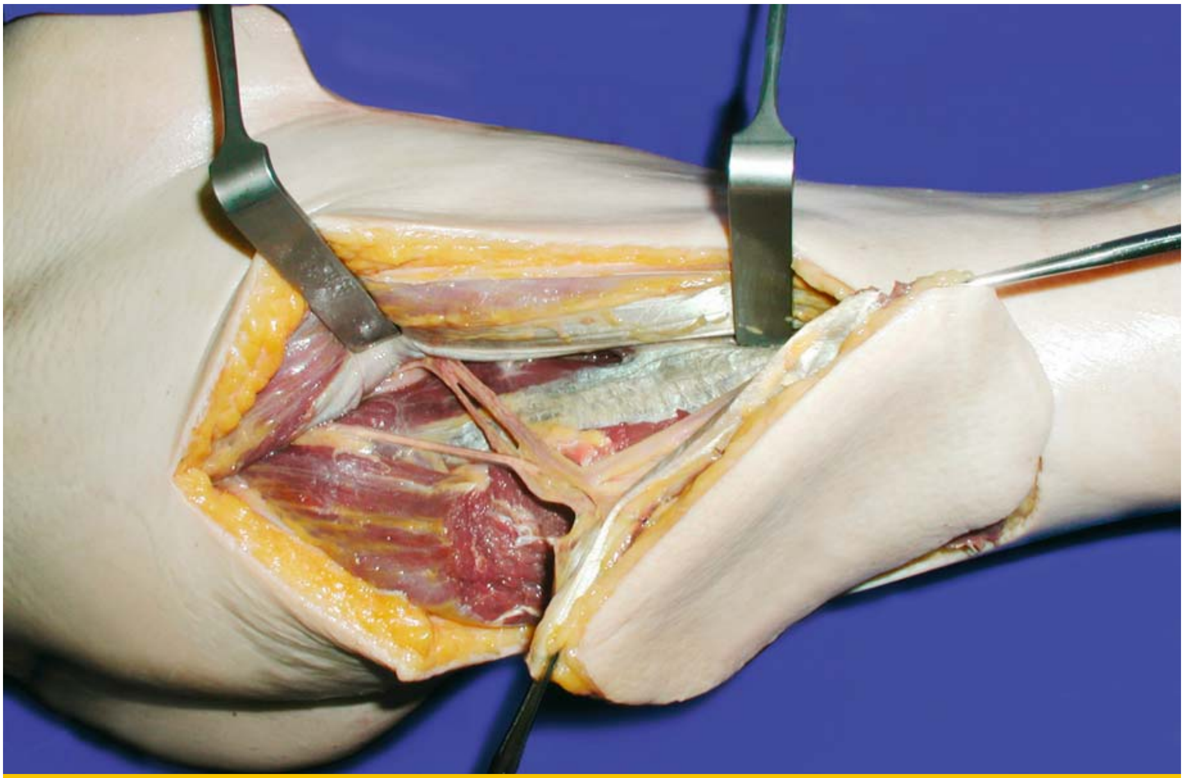
Step 8 • Fixation of skin paddle to muscle, further exposure of vascular pedicle



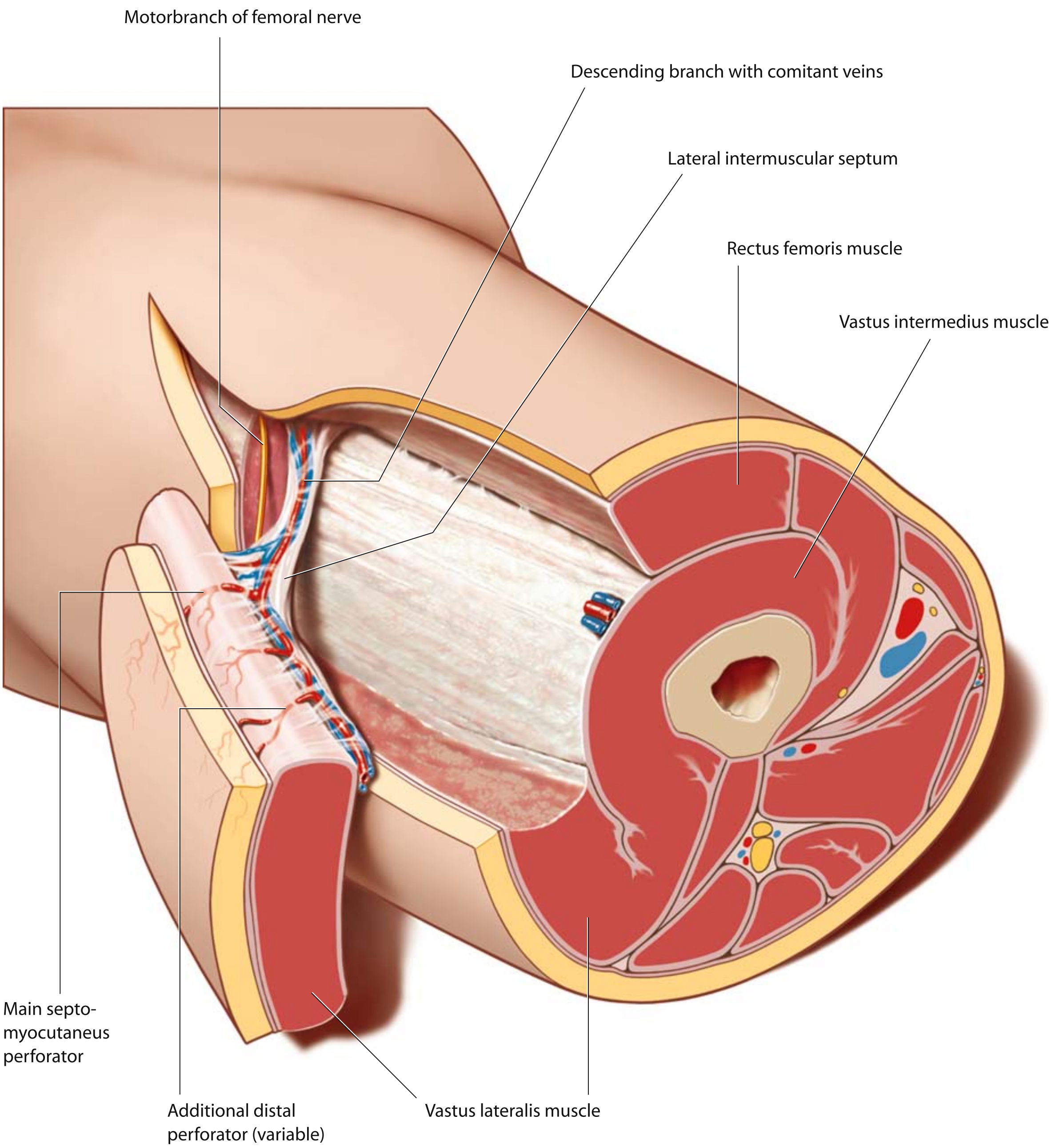
Step 9 • Raising of muscle component



Step 10 • Dissection of vascular pedicle

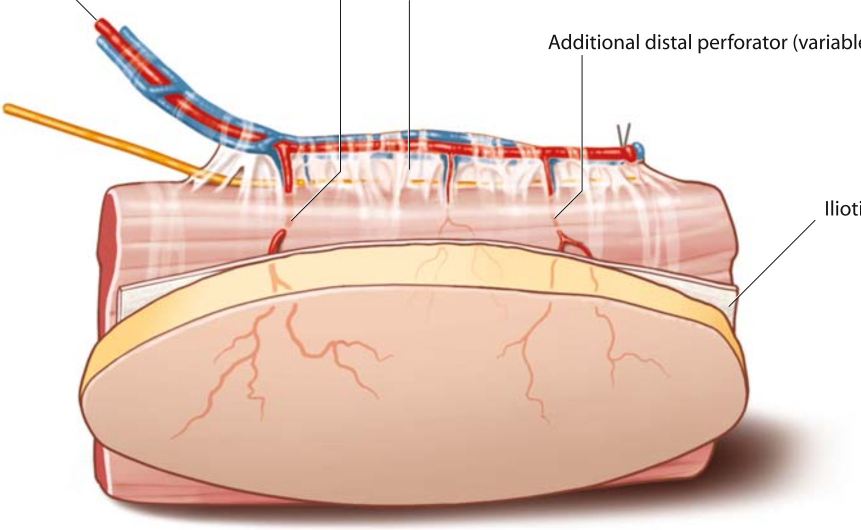


Step 11 • Complete elevation of myocutaneous flap

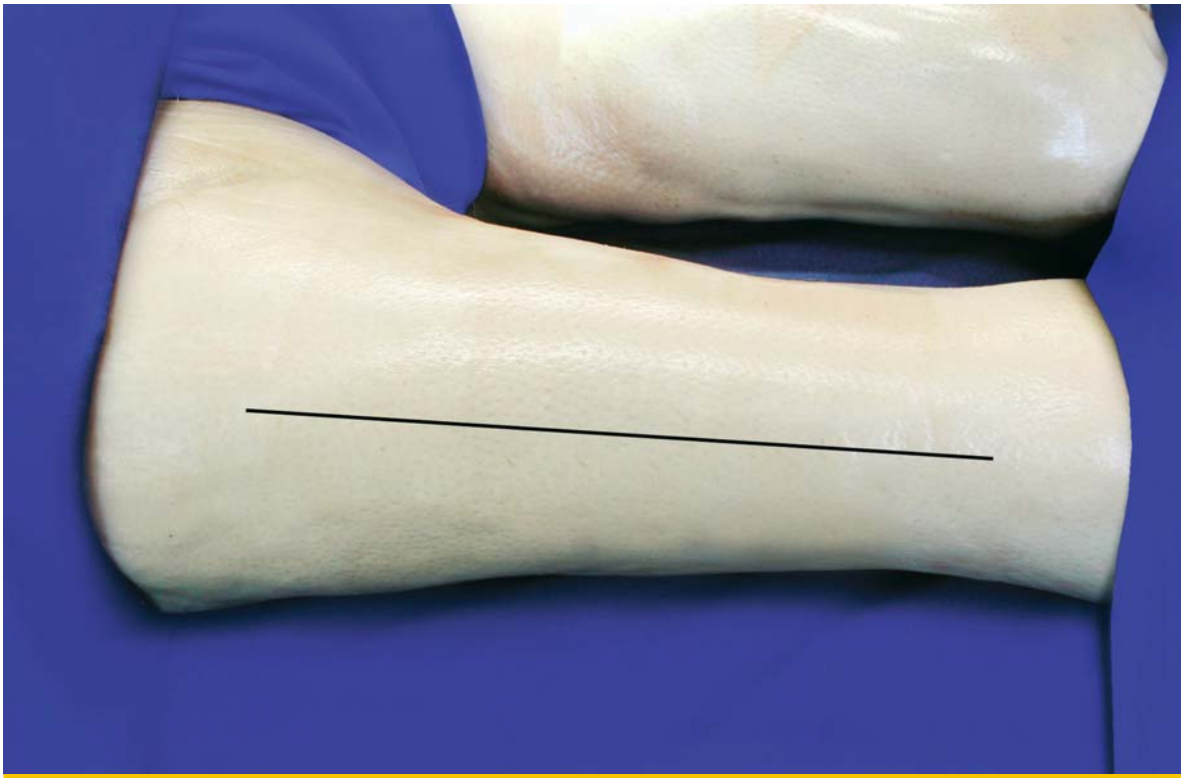


Cross section anatomy of the flap donor site

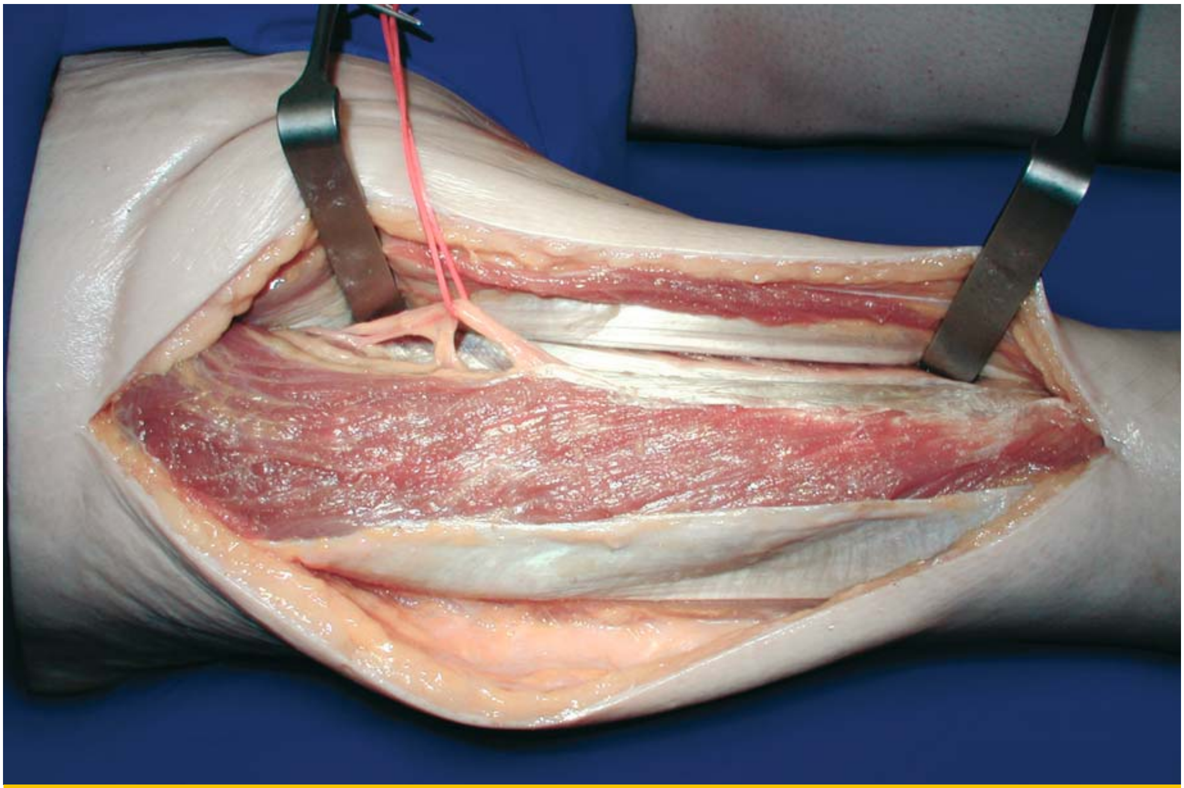
Step 12 • Flap ready for microvascular transfer



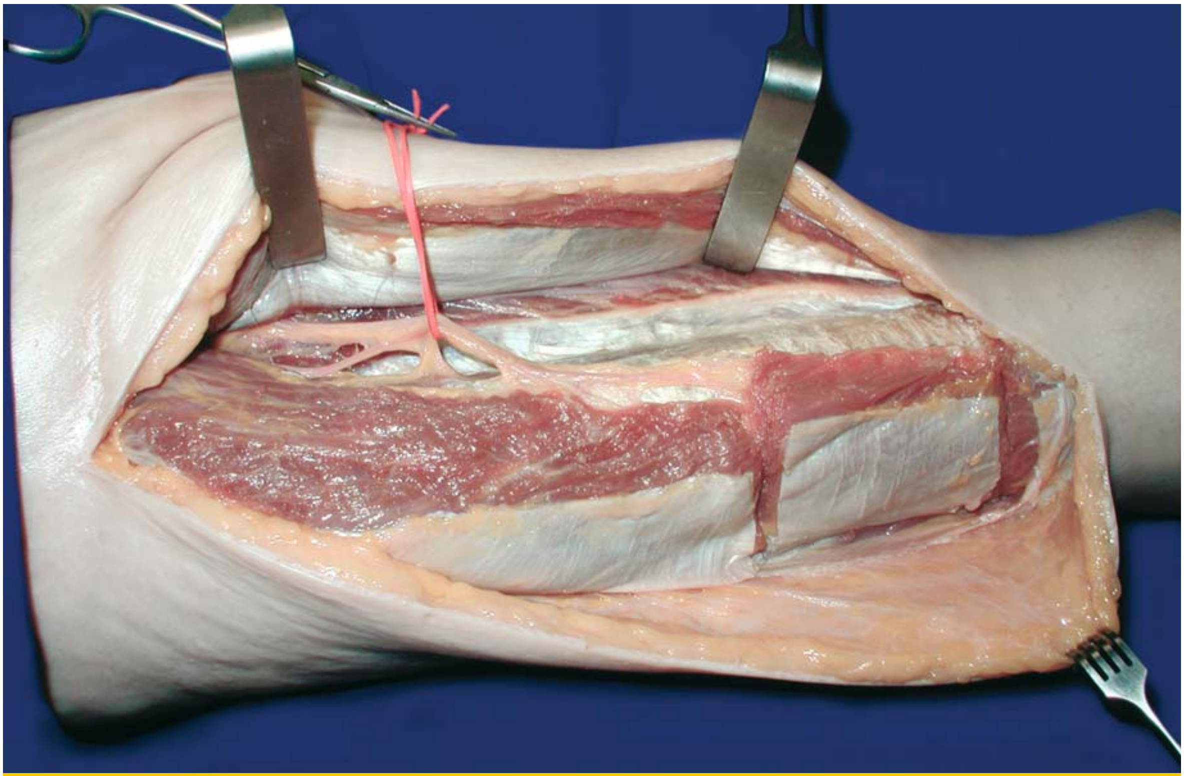
Myocutaneous flap containing two perforators



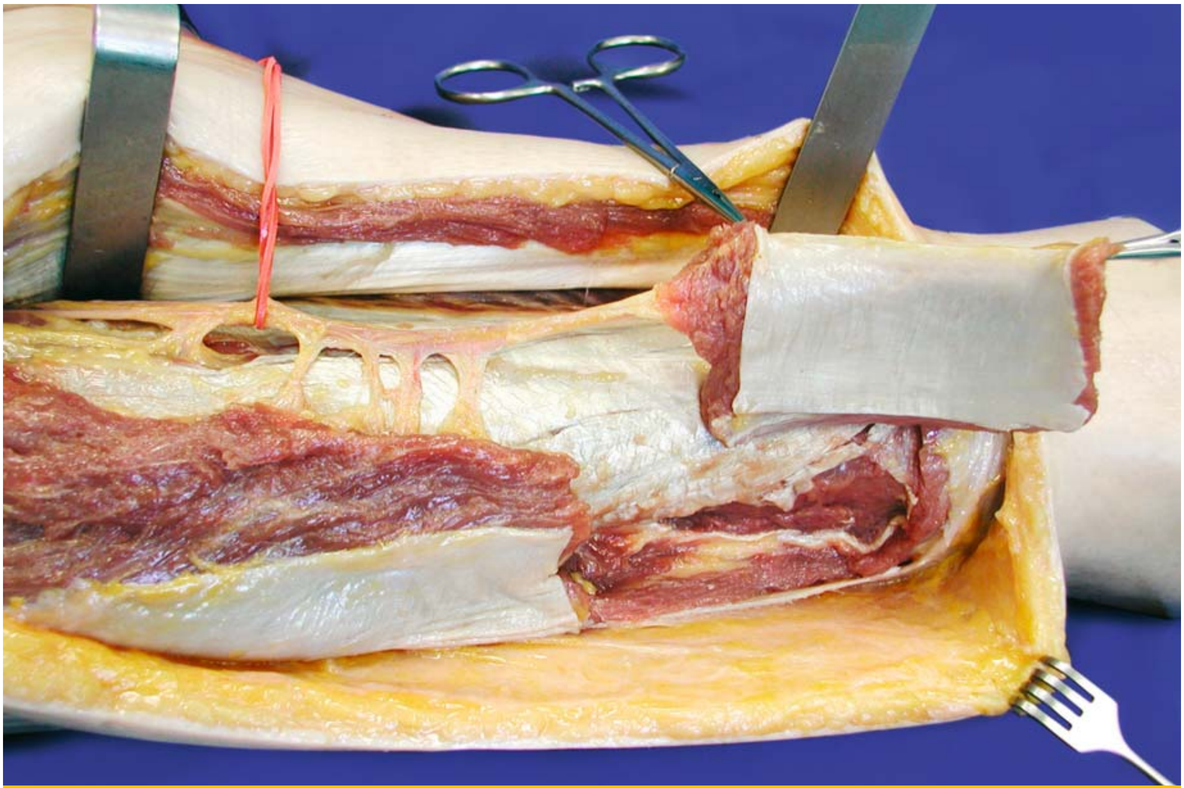
Step 13 • Incision line along lateral intermuscular septum



Step 14 • Proximal exposure of pedicle, incision of fascia and intermuscular septum



Step 15 • Defining of the muscle segment



Step 16 • Elevation of the muscle segment, dissection of pedicle

Step 17 • Myofascial vastus lateralis flap with long pedicle

Comments

Planning

The skin island can never be outlined before the main perforating vessel is exposed. The skin incision to expose the main perforating vessel cannot be outlined lateral to the rectus femoris muscle, because this will lead to injury of the lateral intermuscular septum. Preoperative mapping of the main perforator using an audible Doppler can facilitate planning of the flap design.

Step 1: If the skin incision is performed too far laterally, the cutaneous perforator will be missed or injured. If the skin incision is performed too far medially, exposure of the descending branch may be difficult. Advice: The lateral intermuscular septum can be palpated and marked preoperatively while the patient is extending the leg.

Step 3: If the fascia is incised medial to the rectus femoris muscle, the descending branch cannot be exposed. The rectus femoris muscle should be palpated before the fascia is opened.

Step 4: The cutaneous vessels traveling along the lateral intermuscular septum may easily be injured when the fascia is opened. The use of magnifying glasses may facilitate identification and preservation of the perforators running along the septum. The cutaneous perforators should not be exposed in the level above the fascia to prevent shearing or stretching the tiny vessels.

Step 6: The location, origin, and course of the perforators are variable. Before the skin paddle is outlined, it is important to make sure that the perforator is given off by the descending branch and is piercing the fascia to enter the skin. If the origin of the perforator is not from the descending branch, the transverse or medial descending branch must serve as the vascular pedicle.

Step 9: The cutaneous vessels may be injured if the muscle cuff chosen around the perforators is too narrow. There should be a safe three-dimensional distance around these vessels while dissecting the muscular portion of the flap.

Step 12: Blood flow can be different in both veins accompanying the descending branch. To determine the appropriate vein for anastomosis, venous return should be checked before the artery is transected.

Myofascial Flap

Steps 15, 16: Although the descending branch nourishes the whole vastus lateralis muscle, perfusion of the distolateral part of the muscle can be insufficient; thus, the muscle segment should not be more than 7–8 cm wide and should not be located in the distal quarter of the muscle.

Chapter 4

Latissimus Dorsi Flap

Development and Indications

As the first myocutaneous flap, the latissimus dorsi flap was described in 1896 by Tansini [253] and used for defect cover following radical mastectomy by D'Este in 1912 [56]. Despite its excellent suitability for chest wall reconstruction, the flap did not become popular until the 1970s when a number of publications appeared, in which the previously described advantages were confirmed, and further indications for defect cover in the area of the shoulder and arm were proposed [26, 27, 164, 170, 174, 178, 188, 237]. The first application of a pedicled latissimus dorsi flap for reconstruction in the head and neck area was described by Quillen in 1978 [194], whereas the first microvascular transfer of this flap was performed by Watson in 1979 [276]. In further publications, the reliability and safety of this flap, especially its usefulness for reconstructions in the head and neck area, were demonstrated [97, 166, 167, 199, 200, 232, 276]. In all these reports, a great variety of application possibilities was described. This broad indicational spectrum was possible because of the large amount of tissue available, offering various possibilities for changing the flap design, and the long and high-caliber vascular pedicle, making microvascular anastomoses technically easy [181, 199, 200, 204]. A particular indication of the latissimus dorsi flap is the covering of large perforating defects of the oral cavity, using two skin paddles, which can be outlined along the transverse and vertical branch of the thoracodorsal artery [13, 102, 159, 181]. The inclusion of a rib allows for a osteomyocutaneous transfer and was proposed for reconstruction of the mandible or other parts of the facial skeleton [108, 153, 158]. Another indication of this broad and flat muscle is reconstruction of the scalp, especially when used as a muscle-only flap, which is covered by a skin graft [87, 181, 204, 247], or as a myofascial flap for defect cover at the skull base [202]. Motor reinnervation of the muscle flap has been described by Harii, who connected the thoracodorsal nerve to the facial nerve for rehabilitation of the paralyzed face [98]. For tongue reconstruction, an anastomosis to the hypoglossal nerve was performed [110, 200]. After de-epithelialization, musculosubcutaneous flaps were obtained, which were used for contour augmentations in the head and neck area [65, 181, 200]. In addition to applications in the head and neck area, a lot of other useful indications exist for this very popular free flap, such as reconstructions of the female breast [26, 47, 132], chest wall and axilla [8, 164, 170], shoulder and upper extremities [143, 152], closure of hernias of the diaphragma [18], or other intrathoracic defects [41, 43, 231]. Moreover, defect coverage in the lower extremities [26, 57], the sacrum [215], and treatment of chronic osteomyelitis have been performed using this flap [5, 106].

Anatomy

The latissimus dorsi is a flat, fanlike muscle that arises directly from the spinal processes of the lower six thoracic vertebrae, the lumbar and sacral vertebrae, and the dorsal iliac crest via the thoracolumbar fascia. The muscle inserts between the teres and pectoralis muscles at the humerus and, together with the teres major, it forms the posterior axillary fold. The main nutrient vessel is the thoracodorsal artery which, like the circumflex scapular artery, arises from the subscapular artery. The vascular pedicle travels along the lateral thoracic wall at the undersurface of the latissimus muscle, regularly giving off a strong branch to the serratus anterior muscle. This serratus branch can serve as the vascular pedicle if the thoracodorsal vessels had to be sacrificed during axillary lymph-node extirpation [15, 72, 264]. The length of the extramuscular part of the vessel course varies from 6 to 16 cm and is about 9 cm on average [15]. Besides the aforementioned branch to the serratus muscle, on its extramuscular course, the pedicle regularly gives off another branch to the inferior angle of the scapula, mostly just proximal to the serratus branch [49]. The course of this scapular branch is in the fascial gliding layer between the serratus, subscapularis, and teres major muscles to the scapular bone. Thus, an isolated bone flap from the tip of the scapula that is nourished from the vascular system of the thoracodorsal artery can be raised, and the vascular pedicle of this inferior angle scapular bone flap is about 15 cm on average [226]. Further minor vessels are given off to the teres and subscapularis muscles. The neurovascular hilum where the pedicle enters at the undersurface of the latissimus is 1.5–3 cm away from the anterior muscle rim. At the point of origin from the subscapularis vessels, the thoracodorsal vessels have diameters of 1.5–4 mm (artery) and 3–5 mm (vein after unification of the two concomitant veins) [15]. Whereas the thoracodorsal artery mainly provides blood to the proximal and lateral two-thirds of the muscle, the distal parts of the latissimus dorsi are reached by perforating branches of the intercostal arteries [15]. Thus, the blood supply to the flap can become tenuous when harvested from the distal and medial parts of the muscle. The intramuscular course of the thoracodorsal artery, which is directly accompanied by the thoracodorsal nerve, was investigated in detail by Tobin et al. [264] and Bartlett et al.[15]. According to their findings, shortly after entering the muscle the main vessel divides into a vertical branch, which runs parallel to the anterior border of the muscle, and a transversal branch, running parallel to the proximal muscle rim. With 94.5 % [264] and 86 % [15], this vascular pattern was found to be present in the vast majority of all cases. This constant vascular anatomy provides the basis for dividing the flap into two separate skin paddles and two neuromuscular units. Acryl injections into the arterial system have additionally shown that multiple secondary branches arise from the transversal and vertical branches to the surface of the muscle, forming a dense network of anastomoses [208, 209]. This network allows thinning of the flap by removal of the superficial muscle layers without endangering the blood supply [33, 210]. Although skin paddles can be designed over any part of the muscle, the blood supply can become critical at the caudal and medial parts, where only a few perforating vessels to the skin are found. The highest density of myocutaneous vessels and thus the preferable region for outlining skin paddles is parallel to the anterior or cranial borders of the muscle [15, 264]. Nevertheless, an extended skin flap up to 10 cm long can be built over the distal part of the latissimus muscle, which is safely perfused by myocutaneous perforators from a proximal myocutaneous portion of the flap [102]. Because of the high density of myocutaneous perforating vessels, large skin paddles can be built along the anterior muscle border, harvesting only a narrow strip of muscle that contains the vascular pedicle [153]. Although from an anatomical point of view flap dimensions can be extended as far as 30 × 40 cm [211], the ability to achieve direct wound closure limits the size of the flap; thus, depending on the patient's body shape, the flap width should not exceed 10 cm [202]. In addition to this wide and safe perfusion of the latissimus muscle and overlying skin, the thoracodorsal artery contributes to the blood supply of the scapular bone, which was investigated by Coleman and Sultan [49]. According to their findings, an angular branch, nourishing the tip of the scapula, branches off from the thoracodorsal artery just proximal to the serratus branch (58 %] or from the serratus branch directly (42 %), allowing osteomyocutaneous transfer of the latissimus dorsi flap. This extension of flap raising can be useful for reconstruction of the anterior mandible by giving the bone a horizontal orientation to replace the interforaminal segment [125].

There are only few variations of the vascular anatomy described in the literature, none of them affecting the possibility of raising the flap. Whereas the subscapular artery and vein arise close to each other from the axillary vessels in the majority of patients, the subscapular artery can have a distance of up to 4 cm from the vein in rare cases. Moreover, the thoracodorsal artery may arise directly from the axillary artery [15]. Satoh et al. described a rare variation of blood supply to the latissimus dorsi in a clinical case where the vascular pedicle was only rudimentally present, so that anastomoses had to be performed to the circumflex scapular vessels, which were found to perfuse the muscle instead of the thoracodorsal vessels [219].

Advantages and Disadvantages

The advantages of the latissimus dorsi flap overcome its few disadvantages very clearly: Because of its constant vascular anatomy, the high density of myocutaneous perforators to the overlying skin, the long and high-caliber vessels and because of the ease of flap raising, the latissimus dorsi is a popular and safe flap, offering numerous possibilities for defect cover. Normally, the morbidity of the donor site is low, but this can increase if a radical neck dissection with sacrifice of the accessory nerve is performed simultaneously. Under these circumstances, stability of the shoulder can be reduced [273]. Although a reduction of function and strength of the shoulder generally is not noticed by most patients, some sport activities can be negatively affected [132, 138, 202]. Whereas Laitung and Peck found good compensation of the latissimus function by other muscle groups even in patients active in sports [141], Russel and coworkers noted a weakness of all muscles surrounding the shoulder operated upon [211]. The most significant disadvantage of the latissimus dorsi flap is the difficulty of flap raising simultaneous to tumor resection in the head and neck area [9, 187]. When bringing the patient in a lateral decubitus position prior to flap harvesting, care must be taken to stabilize the contralateral shoulder to prevent injury to the brachial plexus [167, 300]; otherwise, a weakness or paralysis of the radial nerve [195] or permanent loss of sensation [16] or complete motor function [148] in the upper extremity can occur. If the donor site has to be covered by skin grafting, the aesthetic result always is poor, so that flaps should not be outlined broader than 10 cm [153; 187]. Despite the flat shape of the muscle, the myocutaneous latissimus dorsi flap is often too bulky for small and medium-sized defects of the oral cavity, because a considerable layer of adipose tissue between the muscle and skin is found in many patients. When used for facial contour augmentation, the subsequent atrophy of the muscle component can lead to unfavorable secondary volume loss [202].

Flap Raising

Patient Positioning

The patient is brought into a lateral decubitus position and a pad is placed between the shoulder and the neck on the contralateral side to prevent impingement of the brachial plexus by the clavicle. The ipsilateral arm is included in the operating field to allow for free movement, and prepared and draped together with the lateral thorax, shoulder, axilla, and back. If the patient is in a prone position, which is also possible for flap raising, repreparation and redraping must be performed before the operation is continued with the patient in supine position.

Flap Design

Although skin paddles can be designed with a high variability over the whole proximal two-thirds of the muscle, in a standard situation it is highly recommended that the skin paddle be outlined over the anterior part of the latissimus dorsi with the flap axis running 4–5 cm dorsal to the anterior edge. The anterior border of the skin paddle should not exceed the rim of the muscle, and the flap width should be limited to 10 cm to allow primary closure. For exposure of the pedicle, a straight incision is marked from the proximal pole of the flap to the axilla. Correct placement of the skin paddle must carefully be checked by palpating the anterior muscle rim, which forms the posterior axillary groove. Because of the constant anatomy of the pedicle and the high number of perforators, no preoperative measures are necessary before flap raising if no previous surgery (lymphadenectomy) has been performed in the axilla.

Flap Raising

Step 1

The initial incision is made along the anterior border of the skin paddle and continued into the axilla from the upper pole of the flap. The subcutaneous fatty tissue, the amount of which can vary considerably, is transected perpendicularly until the muscle fibers are reached. The anterior rim of the latissimus muscle is exposed by dissecting the fatty tissue away from the serratus muscle and retracting it in an anterior direction. The fat underlying the skin paddle may not be separated from the latissimus muscle.

Step 2

When the anterior border of the latissimus has been clearly identified, by further retracting the skin and subcutaneous fatty tissue in an anterior direction, a branch of the thoracodorsal artery is exposed that supplies the serratus anterior muscle. This strong vessel is the first branch of the thoracodorsal artery that becomes visible. The serratus branch now is traced proximally, leading directly to the vascular pedicle. Additionally, the thoracodorsal artery can easily be located by palpating its pulsation underneath the proximal muscle rim.

Step 3

The anterior rim of the muscle is elevated and retracted, so that dissection of the vascular pedicle can be carried out. The serratus branch leading to the thoracodorsal vessels is preserved until the end of flap raising. Now, the pedicle is dissected in the cranial direction. A second side branch of the thoracodorsal vessels becomes visible opposite the serratus branch, which runs to the inferior angle of the scapula. Depending on the desired pedicle length, the thoracodorsal vessels are followed up to the axilla until the circumflex scapula vessels are reached. Dissecting caudally, the neurovascular hilum is found about 2–4 cm distal to the serratus branch, where the thoracodorsal vessels enter the muscle at its undersurface. Here, the vein is located lateral to the artery, and the motor nerve runs between the vessels.

Step 4

A vessel loop is placed around the neurovascular pedicle inferior to the serratus and scapular branch, and the latissimus dorsi muscle is further undermined by blunt dissection. Careful hemostasis is necessary, especially in the distal and medial parts, where segmental branches of the intercostal arteries additionally supply the latissimus dorsi muscle.

Step 5

The skin paddle is now completely circumcised to the muscle fascia. The muscle is elevated, and then transection of the muscle fibers is performed along the inferior pole of the flap. The anterior border of the skin paddle corresponds to the anterior muscle rim. Therefore it is not necessary to transect the latissimus dorsi along its anterior rim.

Step 6

The posterior parts of the latissimus dorsi muscle can now easily be undermined and elevated by hooks, and the fibro-fatty tissue between the latissimus and the serratus muscle is divided.

Step 7

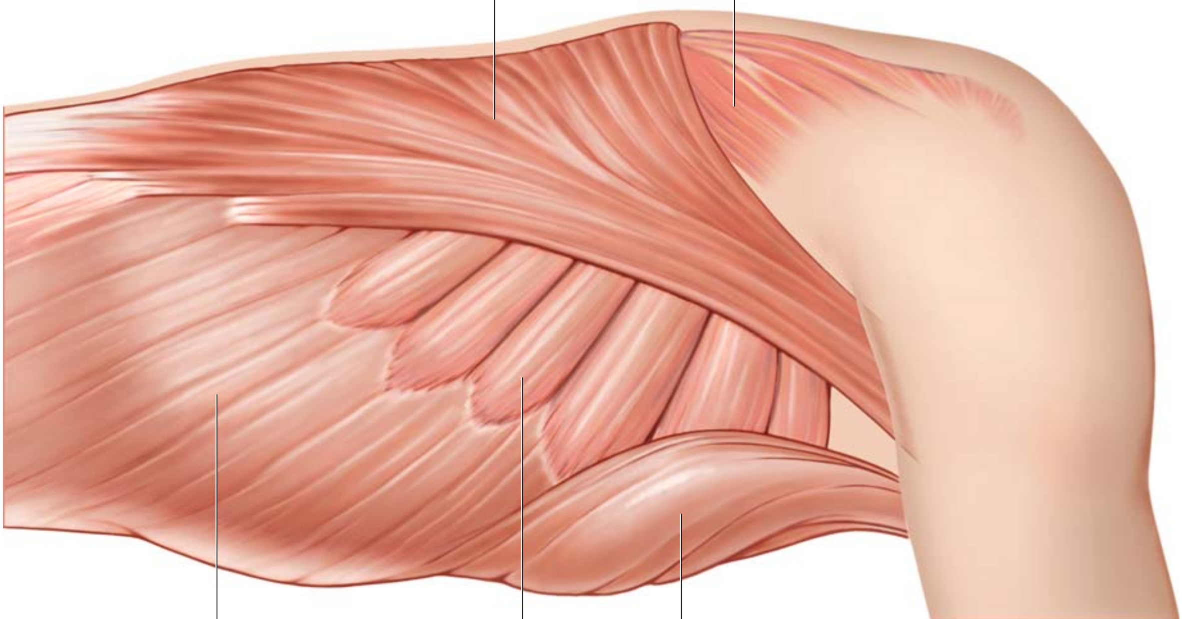
According to the dimensions of the skin paddle, the muscle is transected along its posterior periphery. The neurovascular pedicle is slightly retracted from the muscle to visualize exactly the neurovascular hilum in the region of the cranial pole of the flap.

Step 8

The latissimus dorsi is now completely divided cranially to the neurovascular hilum, creating a strip of muscle between the cranial pole of the skin paddle and the vascular hilum, which carries the vertical branch of the thoracodorsal vessels. The horizontal branch traveling along the superior border of the latissimus dorsi muscle is transected at the cranial flap pole shortly after bifurcation of the thoracodorsal vessels. To ensure safe protection of the vertical branch, which runs 1.5–3 cm away from the anterior border, this strip of muscle should be about 4–5 cm broad.

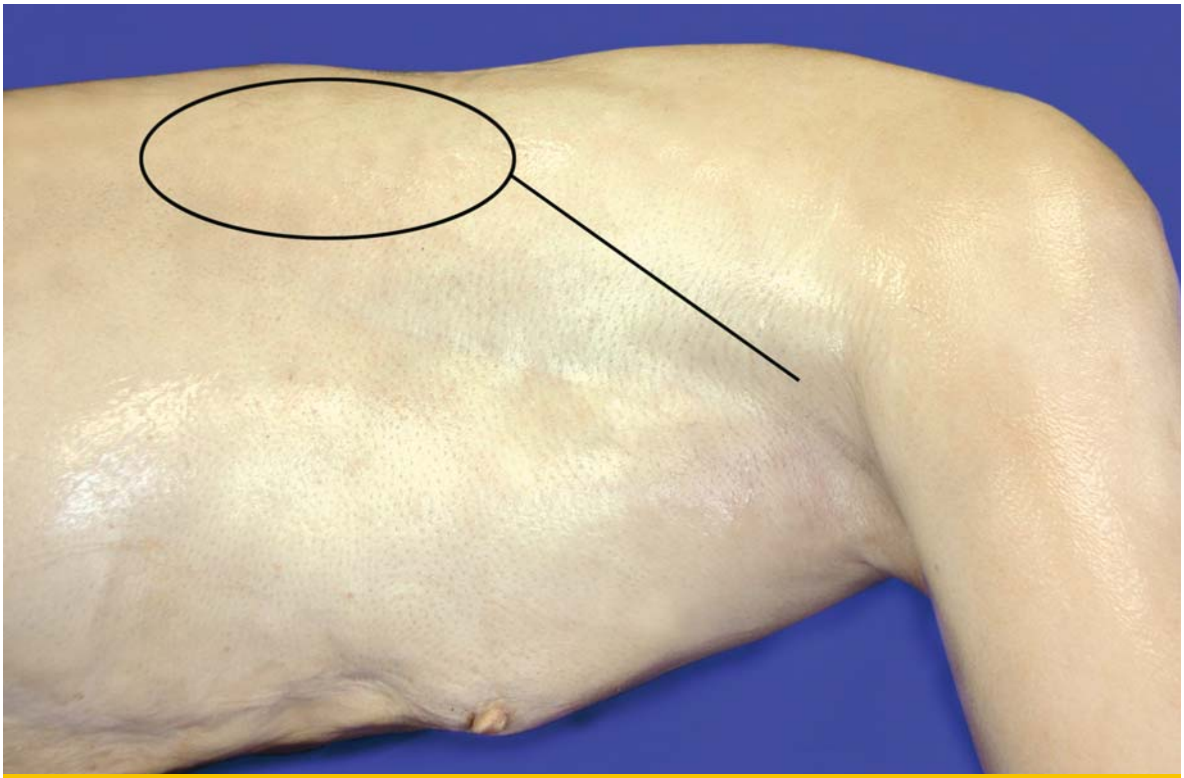
Step 9

Finally, the side branches of the thoracodorsal vessels to the serratus muscle and the inferior angle of scapula are divided. The flap is now ready for microvascular transfer. Because of their strong caliber, artery, vein, and nerve can easily be separated from each other. The thoracodorsal nerve can be used for flap reinnervation. Perfusion of the flap is maintained until the recipient vessels are prepared for anastomoses. A drain is inserted, and direct wound closure is achieved after mobilization and hemostasis.

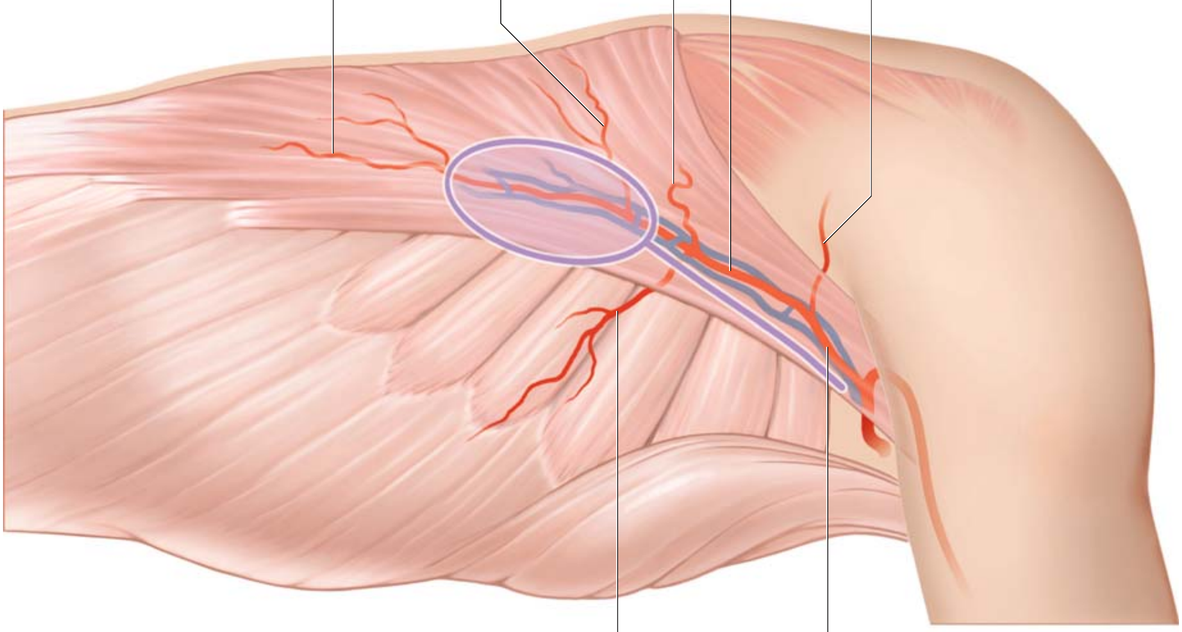


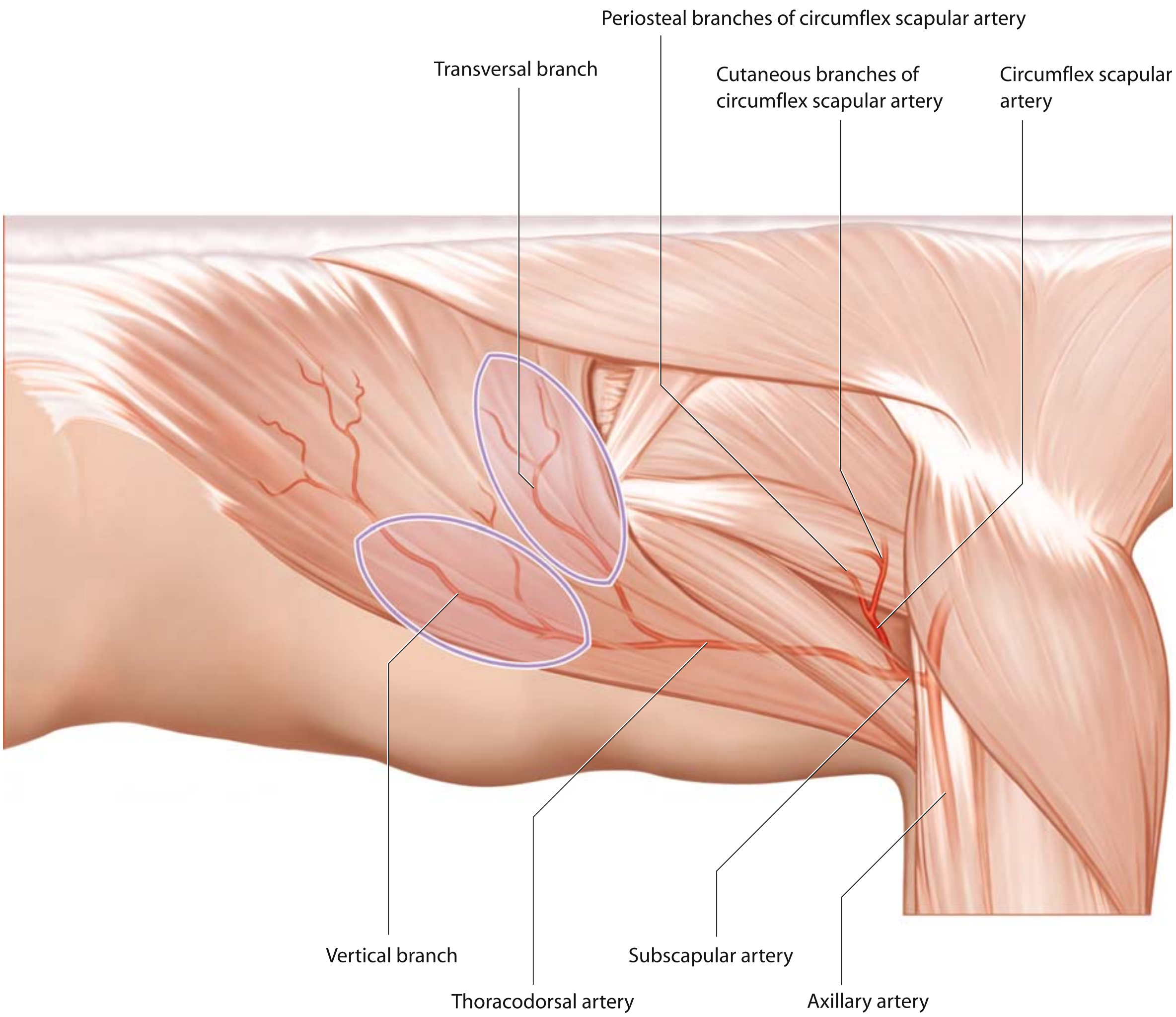
Muscle anatomy of the lateral thoracic wall

Vascular system of the latissimus dorsi muscle and standard flap design ▶



Standard flap design along anterior muscle rim

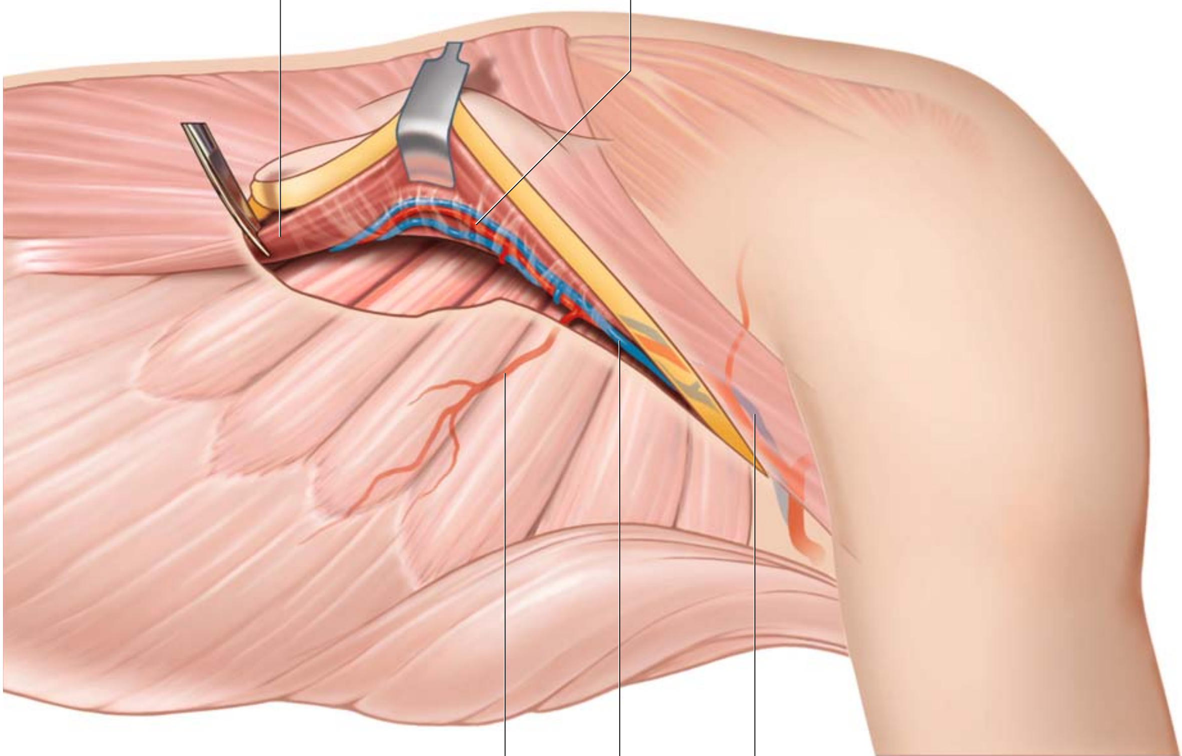




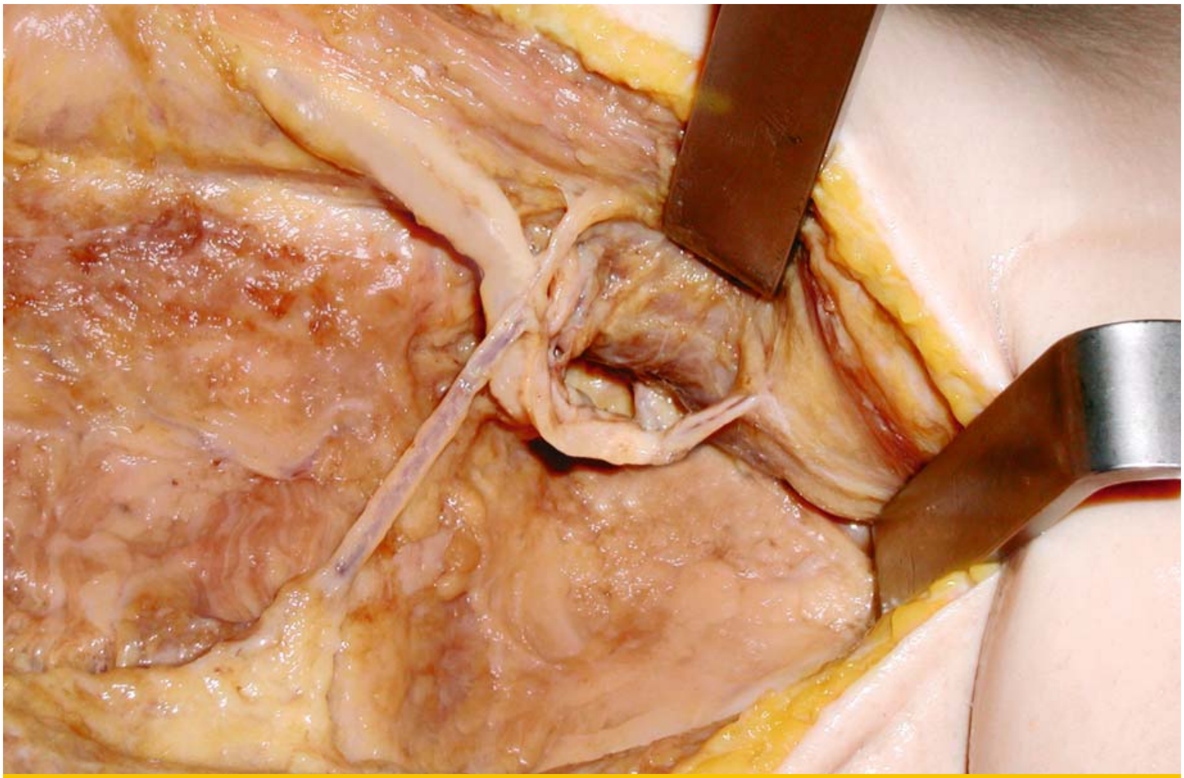
Second skin paddle placed along the transversal branch

Step 1 • Skin incision and exposure of anterior rim of latissimus dorsi muscle

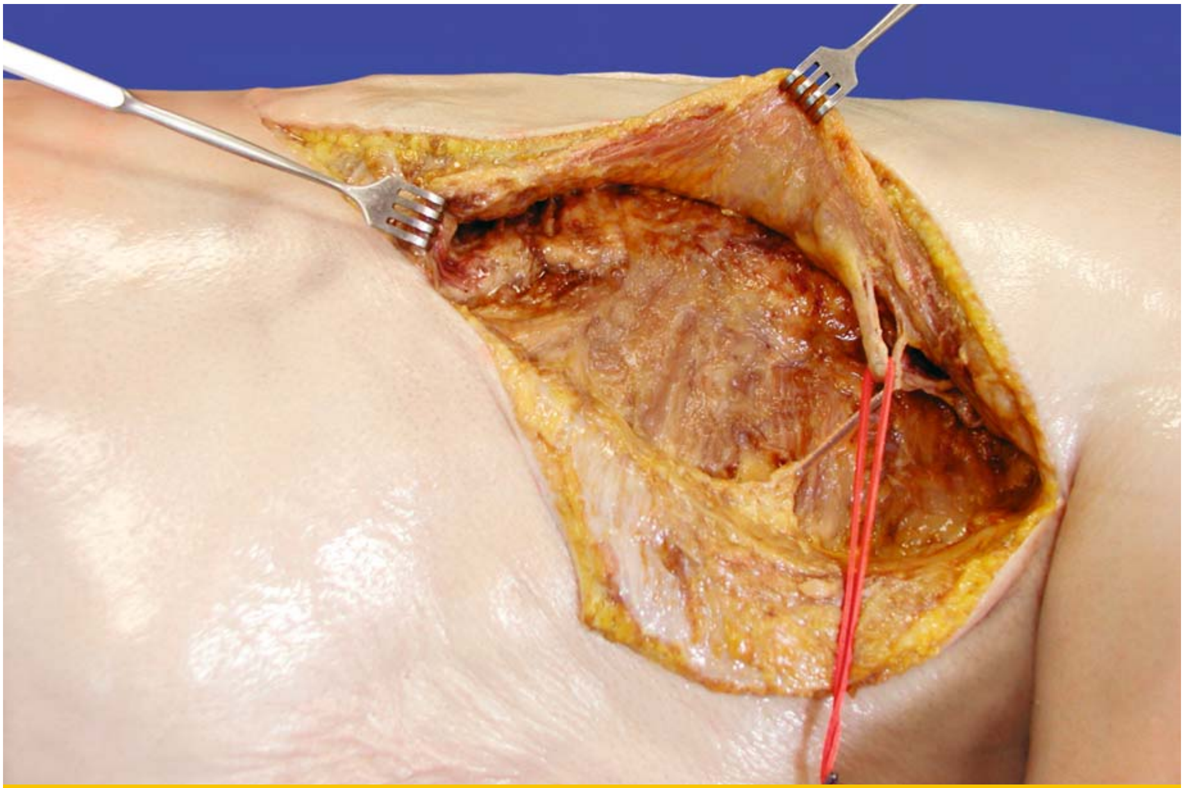
Step 2 • Identification of anterior muscle rim and serratus branch



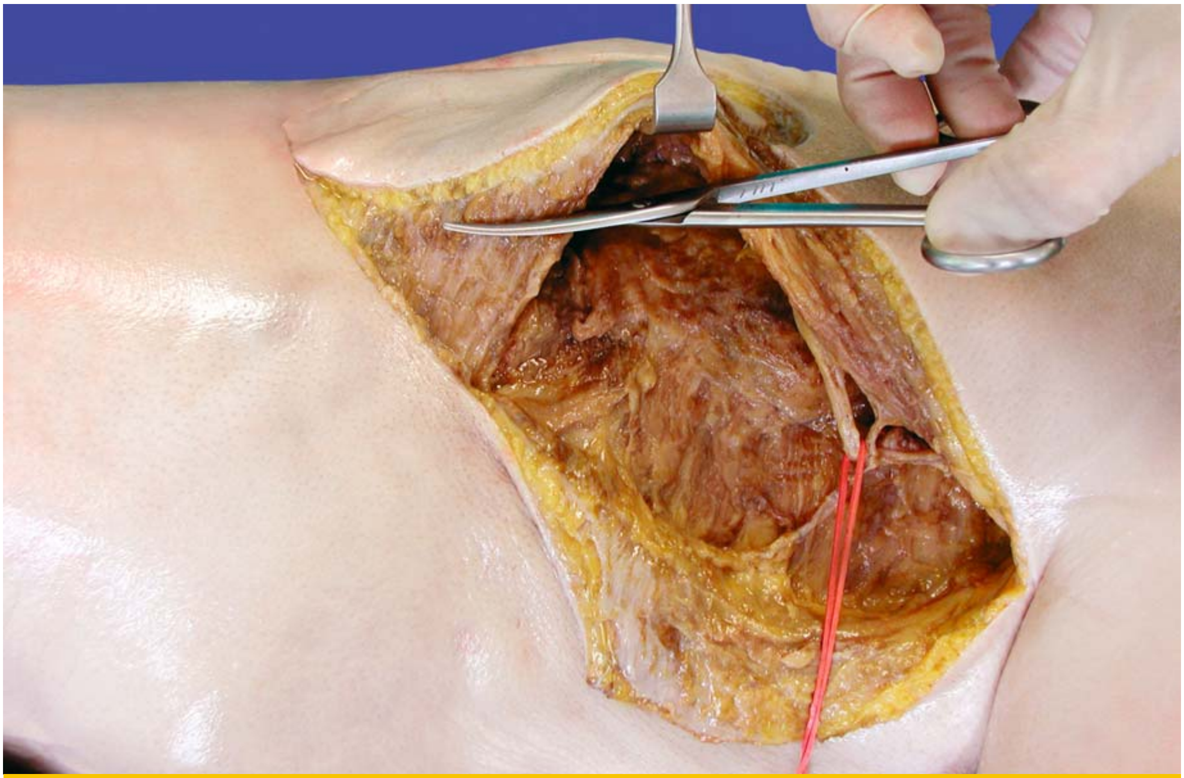
Anatomic relation of serratus branch, anterior muscle rim and thoracodorsal vessels



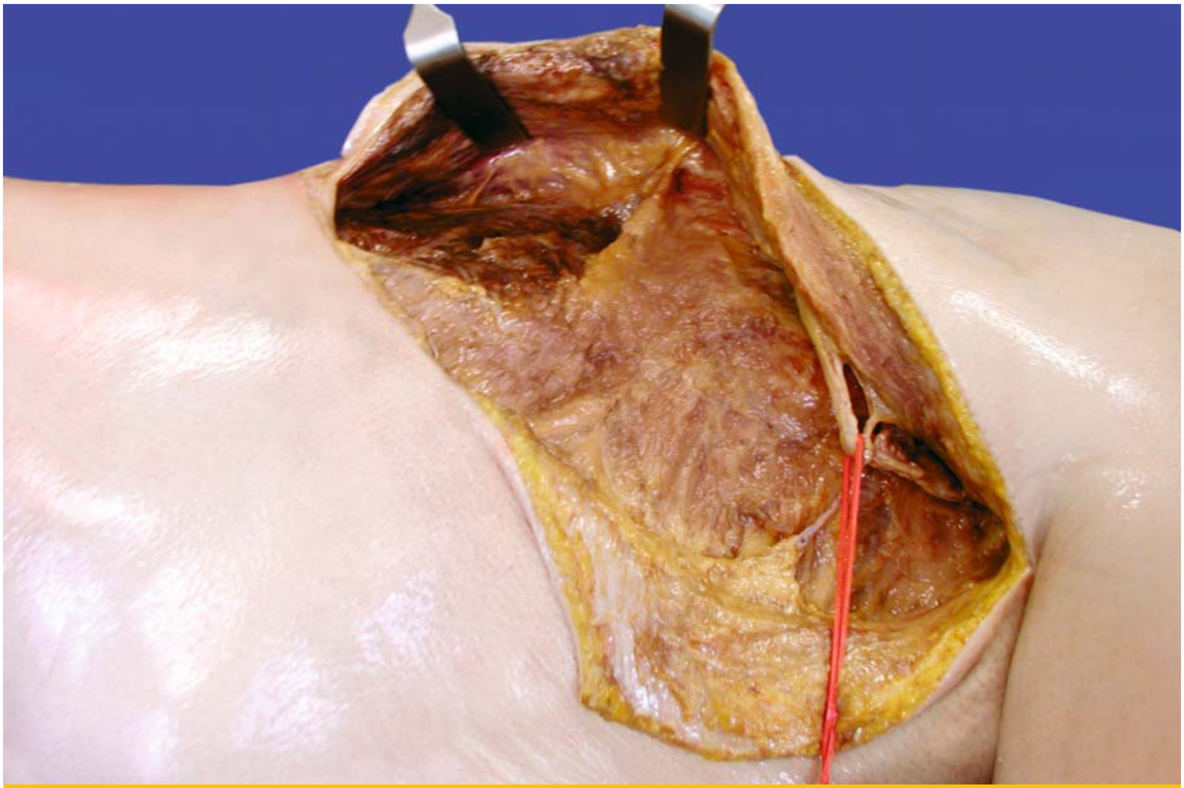
Step 3 • Dissection of neurovascular pedicle and side branches



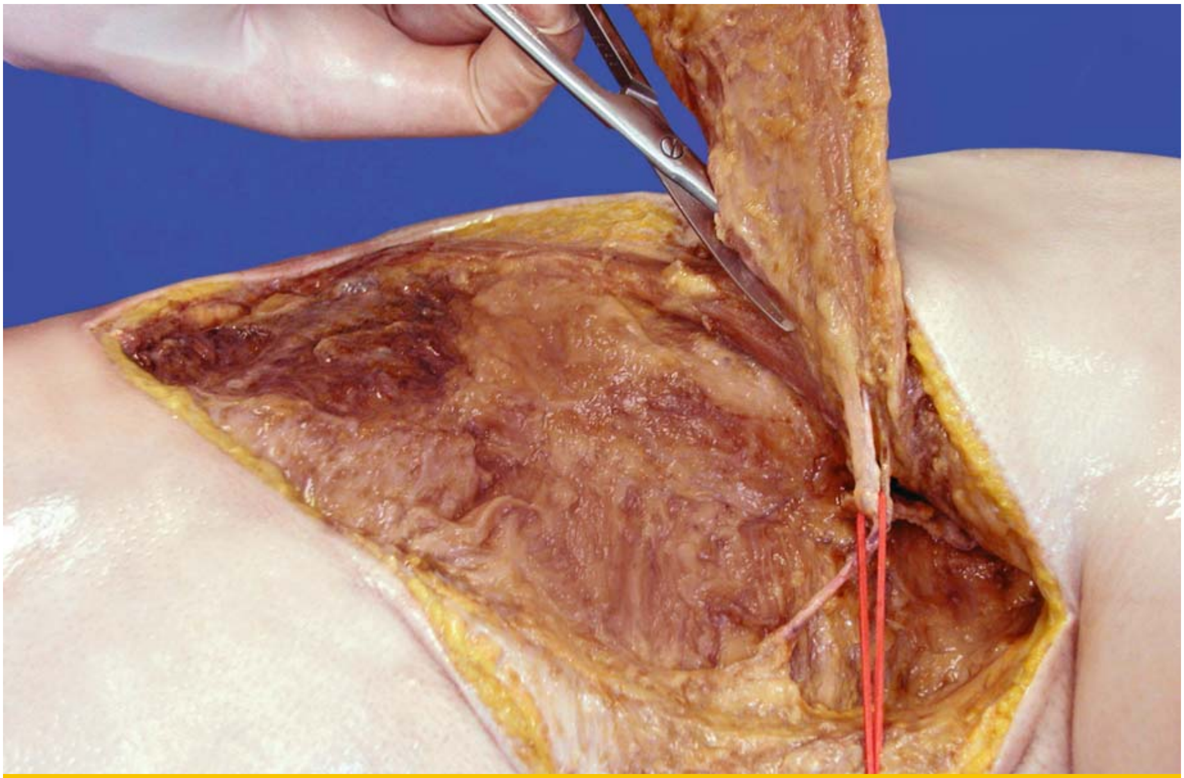
Step 4 • Undermining of the latissimus dorsi muscle



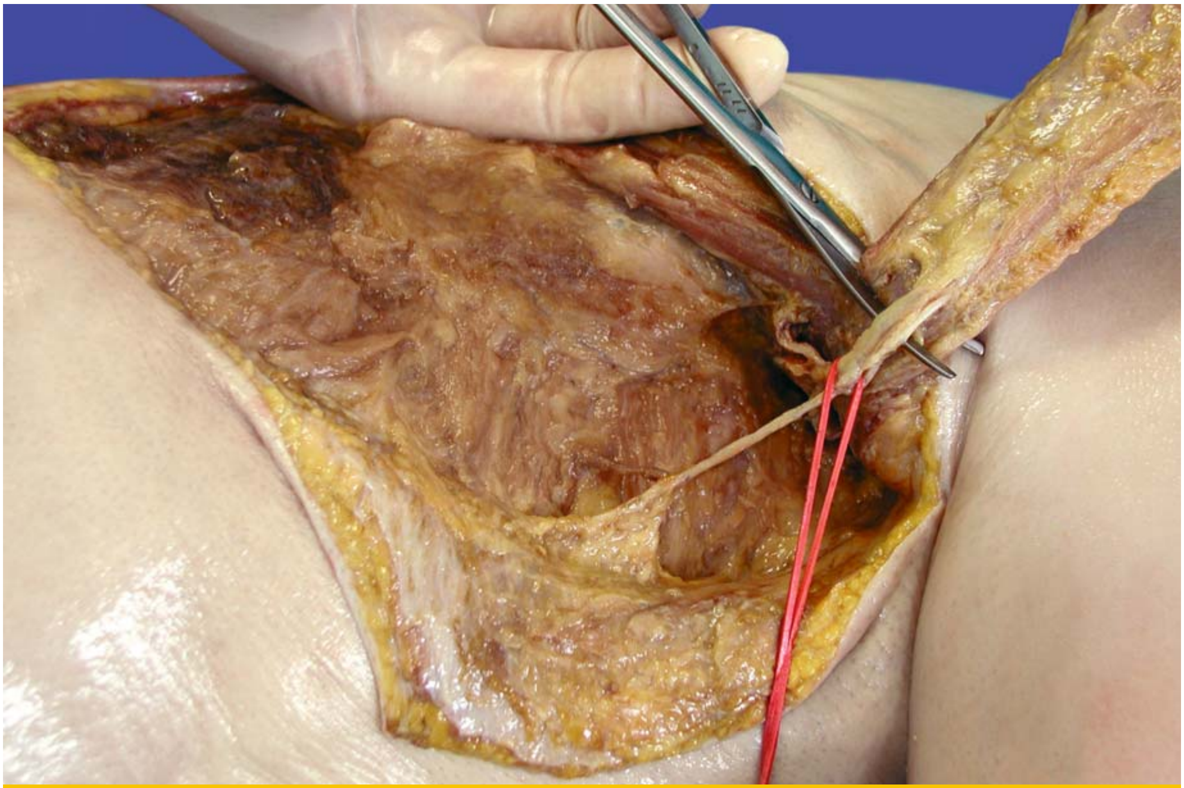
Step 5 • Muscle transection at inferior flap pole, complete circumcision of skin paddle



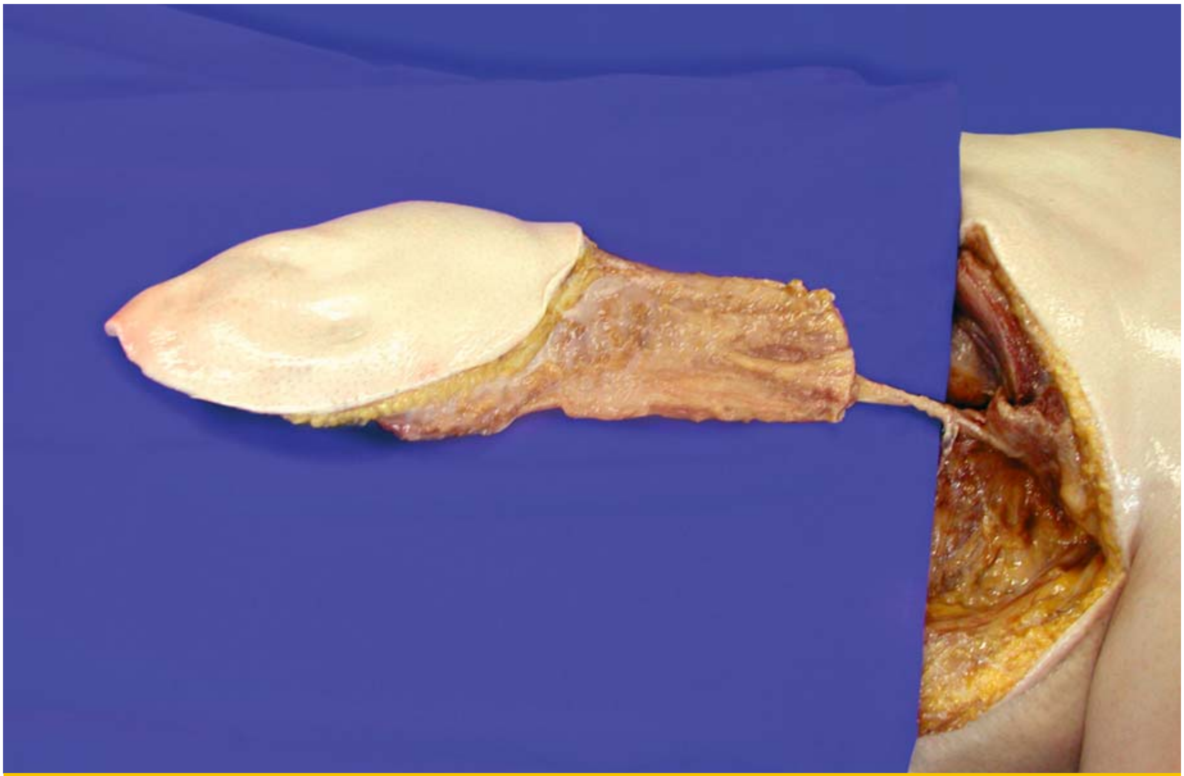
Step 6 • Further elevation of latissimus muscle



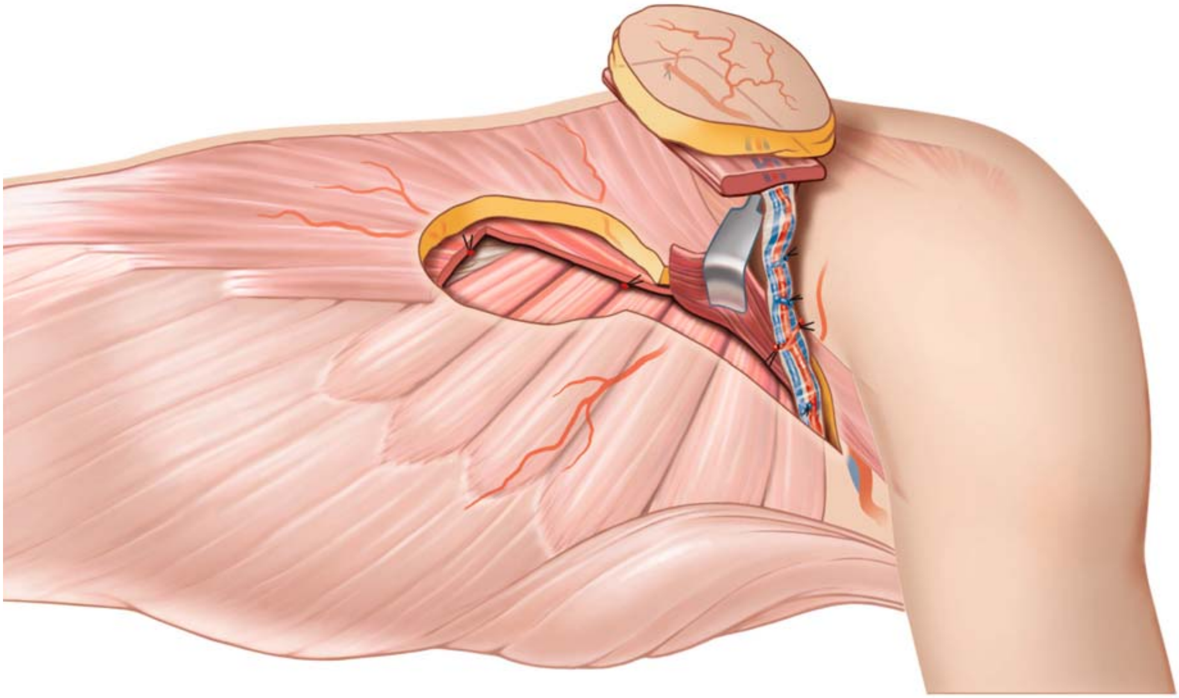
Step 7 • Transecting the latissmus dorsi muscle along the posterior periphery of the flap



Step 8 • Complete division of muscle fibers superior of flap hilum



Step 9 • Elevated flap still attached to the neurovascular pedicle



Raised flap containing a dense network of myocutaneous perforators

Comments

Step 1: The anterior border of the latissimus muscle can be missed, especially in obese patients. To determine its location, a line is drawn between the dorsal axillary fold and the midline of the iliac crest. In slim patients, the muscle rim can easily be palpated and marked preoperatively during active adduction of the arm by the patient. Advice: First expose the anterior muscle rim proximal to the skin paddle to determine exactly the position of the anterior flap border, which should not exceed the muscle.

To estimate the amount of skin that can be removed to still allow for direct wound closure, a large fold of skin should be pinched at the flap site.

Step 2: The serratus branch should not be mistaken for the thoracodorsal artery. This vessel should not be transected or ligated before the thoracodorsal artery is clearly identified.

Step 3: Proximal dissection of the vascular pedicle is facilitated if the skin incision is extended to the onset of the posterior axillary fold. At the level of the circumflex scapular vessels, the length of the thoracodorsal artery to the neurovascular hilum of the flap is at least 7 cm.

Step 5: To prevent shearing forces to the perforating vessels, the skin paddle should be fixed to the muscle with some stay sutures.

Step 7: If the strip of muscle is too narrow, the vertical branch of the thoracodorsal artery may be missed. Advice: Flap raising is facilitated and more reliable if the muscle component is nearly the same size as the skin paddle.

Step 8: Clearly visualize the neurovascular hilum before the muscle is transected cranially.

Step 9: The stay sutures between the skin paddle and the muscle should not be removed until the flap is fixed at the recipient site. If the vascular pedicle is not dissected up to the subscapular artery and vein, the larger of the two concomitant veins should be used for anastomosis.

Chapter 5

Scapular Flap

Development and Indications

The subscapular vascular system and its suitability for flap harvesting first were investigated in an anatomical study by Saijo in 1978 [214]. Two years later, Dos Santos made use of these previous anatomical findings [61]. He described the scapular flap as a lipocutaneous flap, nourished by a transverse septocutaneous branch from the circumflex scapular artery. This flap, the axis of which was oriented inferior and parallel to the scapular spine, was successfully transferred by Gilbert in 1979 [82]. Following further and more detailed anatomical studies[83, 168, 260], a number of clinical series were reported using this flap, which soon was accepted as another useful tool for coverage of soft-tissue defects [17, 84, 94, 265, 268]. A variation of this flap was described in 1982 by Nassif and coworkers, who proposed using the descending septocutaneous branch of the circumflex scapular artery as the nourishing skin vessel [184]. Thus they designed the skin paddle of this parascapular flap along the lateral border of the scapula. In 1981, Teot and coworkers reported that from an anatomical point of view, all of the preconditions are fulfilled for building a purely osseous flap from the scapula bone [260]. Nevertheless, it was still 1986 before it first became popular to harvest osteocutaneous flaps by including the lateral border of the scapula [236, 250]. Since that time, the indications for flaps raised from the scapular donor site have been considerably expanded [12, 66, 236, 250]. Because the vascular pedicle develops from the same source artery as the latissimus dorsi flap, both flaps can be combined, using only one set of anastomoses at the subscapular vessels [185]. The indicational spectrum of flaps raised from the scapular region in the head and neck area thus stretches from contour augmentations using de-epithelialized adipofascial flaps to closure of extended perforating composite defects with simultaneous mandible reconstruction using osteomyocutaneous scapular and latissimus dorsi flaps [12, 49, 50, 65, 125, 198, 202, 267]. Moreover, a number of useful applications were soon described for defect cover in the upper [30, 73, 109] or lower extremities [38, 54, 83, 134, 227].

Anatomy

The circumflex scapular artery represents one of the two main branches of the subscapularis artery, which has a diameter of 3–4 mm at its origin from the distal third of the axillaris artery [153]. During its course to the scapula region, the artery, which is accompanied by two veins, has to penetrate the triangular space. This triangle is built by the teres muscles and the long head of the triceps. After giving off small branches to the surrounding muscles, the circumflex scapular artery divides into a deep and superficial branch. The first branch runs underneath the teres major muscle and divides into terminal branches to reach the periosteum of the lateral border of the scapular bone. The second main branch, the superficial branch of the circumflex scapular artery, divides into the transverse and descending cutaneous branch to perfuse the scapular and parascapular skin flap, respectively. The blood supply to the periosteum of the scapula was investigated by Coleman and Sultan [49]. According to their findings, an angular branch nourishing the tip of the scapula arises from the thoracodorsal artery just proximal to the serratus branch in 58 % of all cases, so that the tip of the scapula can be transferred on the thoracodorsal vessels as well. This angular branch was first described by Deraemacher et al., who reported the possibility of transferring the tip of the scapula together with the serratus anterior muscle on the thoracodorsal artery [59]. In a detailed anatomical study, the angular branch was found to travel between the serratus, subscapular, and teres major muscle to the inferior angle of the scapula.

Although the transverse branch was found always to be present with a diameter of 1.5–2.5 mm in more than 100 cadaver dissections [62, 83, 268], Godina was unable to identify this cutaneous vessel in 3 of 28 clinical cases [84]. When raising the skin paddle as a scapular flap, the flap axis is outlined below and parallel to the spine of the scapula. According to Urbaniak et al., the limits of the skin paddle should be 2 cm below the scapular spine, 2 cm above the angle, and 2 cm lateral to the midline [268]. In an anatomical dissection it was shown that the vascular tree passes the midline and reaches the contralateral acromion [113], but Hamilton pointed out that the maximum length of a scapula skin paddle should not be more than 24 cm and may not reach the midline because of the risk of necrosis of the tip of the skin island [94]. By additionally anastomosing the flap to the contralateral circumflex scapular artery, a 50 × 10 cm large biscapular flap can be harvested [10, 69].

When planning a parascapular skin island, the flap axis is oriented above the lateral scapular border, which can have a length of 25 cm [42] or even 30 cm [229]. Because the terminal branches to the skin form a dense network of anastomoses, building a subdermal and epifascial vascular plexus, fasciosubcutaneous and deep subcutaneous flap compartments can separately be transferred and used for contour augmentations [76, 267]. The length of the vascular pedicle depends on the extent of proximal dissection. If the vascular pedicle is limited to the circumflex scapular artery, its maximum length will be 7–10 cm. Lengthening the pedicle up to 11–14 cm is possible by including the subscapular vessels, transecting these vessels at their point of takeoff from the axillary artery and vein [184]. The circumflex scapular artery is joined by two concomitant veins between 2.5 and 4 mm in diameter. In the majority of cases, these veins unify with the thoracodorsal vein; in 10 %, however, they enter the axillary vein separately [62].

Advantages and Disadvantages

The major advantages of the scapular skin flap become obvious when comparing it with the osteocutaneous flaps of other donor sites: the skin of the scapular flap is mostly hairless and similar to the facial skin in texture and color. It has only a thin layer of adipose tissue, and primary closure of the donor site is possible up to a flap width of 8–10 cm. Moreover, the vascular pedicle can be dissected to an acceptable length and is of high caliber. There are only a few anatomical variations concerning the vascular pedicle, and the flap design can be variable. The possibility of simultaneously raising latissimus dorsi [185] or parascapular flaps, which all can be left pedicled at the same source artery, further expands the indicational spectrum [236; 250]. Up to four flap components can be created, each offering the possibility of free and independent positioning [190; 202]. Because of the specific architecture of the scapula, reconstructions of the maxilla can be performed by using the blade of the bone to replace the hard palate [125; 202; 273]. Primary closure of the donor-site defect mostly is possible even following harvesting of wide flaps, but unacceptable broad scars can result if tension-less wound closure is impossible [153]. Raising combined scapular and parascapular flaps is always limited by the ability to achieve direct wound closure [202]. To avoid the application of skin grafts, pretransfer expansion of the skin has been performed in suitable cases [267]. By prelaminating the bone with dermis and simultaneous insertion of enosseous implants, reconstructions of the alveolar ridge with a mucosa-like surface are possible [221]. Even after harvest of osteocutaneous flaps, which makes transection of the teres muscles necessary, disability of the shoulder is reported to be low [50, 190, 273]. Postoperative care includes immobilization of the arm for 3–4 days and physiotherapy to strengthen the muscles of the shoulder girdle, starting about 2–3 weeks after surgery.

The main disadvantage of the scapular donor site is the fact that simultaneous flap raising is impossible when tumor resections in the head and neck area have to be carried out. In these cases, flap harvesting cannot be started until tumor resection is completed, so that there will be considerable loss of time; additionally, new positioning and reprepping of the patient is also time consuming. Whereas the cutaneous branches normally can be identified quickly, dissection of the vascular pedicle by working through the posterior triangle can be difficult in the raising of cutaneous flaps, especially if a long pedicle is needed [65]. To simplify dissection of the vascular pedicle, Gahhos et al. proposed performing a second incision at the axilla, which facilitates identification of the subscapular vessels [77]. Then, the flap can be pulled towards the axilla to obtain maximum length of the pedicle.

Flap Raising

Patient Positioning

Flap elevation is performed with the patient in a prone or lateral decubitus position. Shoulder, back, lateral thorax and upper arm are circularly prepped to allow for movement of the extremity and exposure of the subscapular system from an axillary approach, if needed. In the lateral decubitus position, bags are used to stabilize the patient and to protect the dependent shoulder. Preoperatively, the location of the lateral circumflex scapular artery (CSA) is identified using Doppler in the triangular space at the lateral rim of the scapula. Because the anatomy is consistent, angiography is only necessary if operations at the donor site (axillary lymphadenectomy) have been performed previously.

Flap Design

Skin paddles can be elevated along the axis of the transverse (scapular flap) or descending branch (parascapular flap) of the CSA. In the standard situation, a scapular flap is outlined, keeping the upper, lower, and medial margins of the flap at least 2 cm away from the scapular spine, inferior angle, and posterior midline. The angle, spine, and lateral border of the scapula have to be palpated before outlining the flap. For both the scapular and the parascapular flap, it is crucial that the lateral part of the skin paddle be outlined above the triangular space, where the CSA runs along the fascial septum between the teres major and minor muscles to enter the posterior thoracic fascia and the skin. This triangular space is found either by palpation of the muscular groove lateral to the scapular bone or, more exactly, by preoperative mapping of the artery using audible Doppler sonography or Doppler imaging. The width of the flap may not exceed 8–10 cm to make direct closure possible. The bone segment is harvested from the lateral scapular border, inferior to the glenohumeral joint and mostly including the inferior angle.

Flap Raising

Step 1

Starting medially, the skin and subcutaneous fatty tissue are incised to the deep fascia overlying the infraspinatus muscle. The fascia, which consists of multiple layers, is included at the undersurface of the flap, but the deepest layer of fascia, directly covering the muscle fibers, is left intact.

Step 2

The dissection proceeds in the lateral direction by bluntly separating the fasciocutaneous flap from the infraspinatus and teres minor muscle until the posterior muscle triangle is reached. Here, the position of the CSA has already been marked at the skin preoperatively using Doppler.

The pulsation of the cutaneous branch, which is enveloped in the fascia, can now be seen and palpated easily. After the cutaneous branch has been exposed, the skin paddle is circumcised at its lateral portion and completely elevated.

Now, the CSA is traced proximally, and the fascial space between the teres minor and major muscles is opened. The lateral margin of scapula is identified by retracting the teres minor medially to expose the perforators to the bone, branching off from the deep segment of the CSA. A vessel loop is placed around the CSA proximal to the bone feeders, which are carefully protected during further flap raising. Step 3

In the close-up view, the deep segment of the CSA is visible, giving off three branches to the proximal lateral border of the scapula. The cutaneous branch courses directly into the undersurface of the skin paddle, where it divides into the horizontal (scapular skin paddle) and the descending branch (parascapular skin paddle). Step 4

To gain access to the scapular bone, the infraspinatus and teres minor muscles are incised 3 cm parallel to the lateral border of scapula, leaving a muscle cuff attached to the bone. The muscle is transected completely, starting at the inferior angle of scapula and ending cranially to the bone feeders. Step 5

Cranially to the branches of the CSA to the bone, the teres minor and infraspinatus muscles are transected perpendicular to the muscle fibers to prepare for the osteotomy. Step 6

The teres major muscle, which originates from the inferior angle and lateral rim of scapula, is separated from the latissimus dorsi at the inferior angle, and the caudal portion of scapula is undermined. Step 7

The teres major is now elevated and undermined, so that the angular branch of the thoracodorsal artery becomes visible. Although this vessel contributes to the blood supply of the tip region, it can be transected without endangering the viability of the scapular bone flap. If an isolated angular bone segment is planned, the vascular pedicle should include the thoracodorsal artery, and the angular branch is left intact. Step 8

The teres major muscle is now transected directly at the lateral border of the scapula. Doing this, the vascular branches of the CSA to the bone must carefully be protected. Step 9

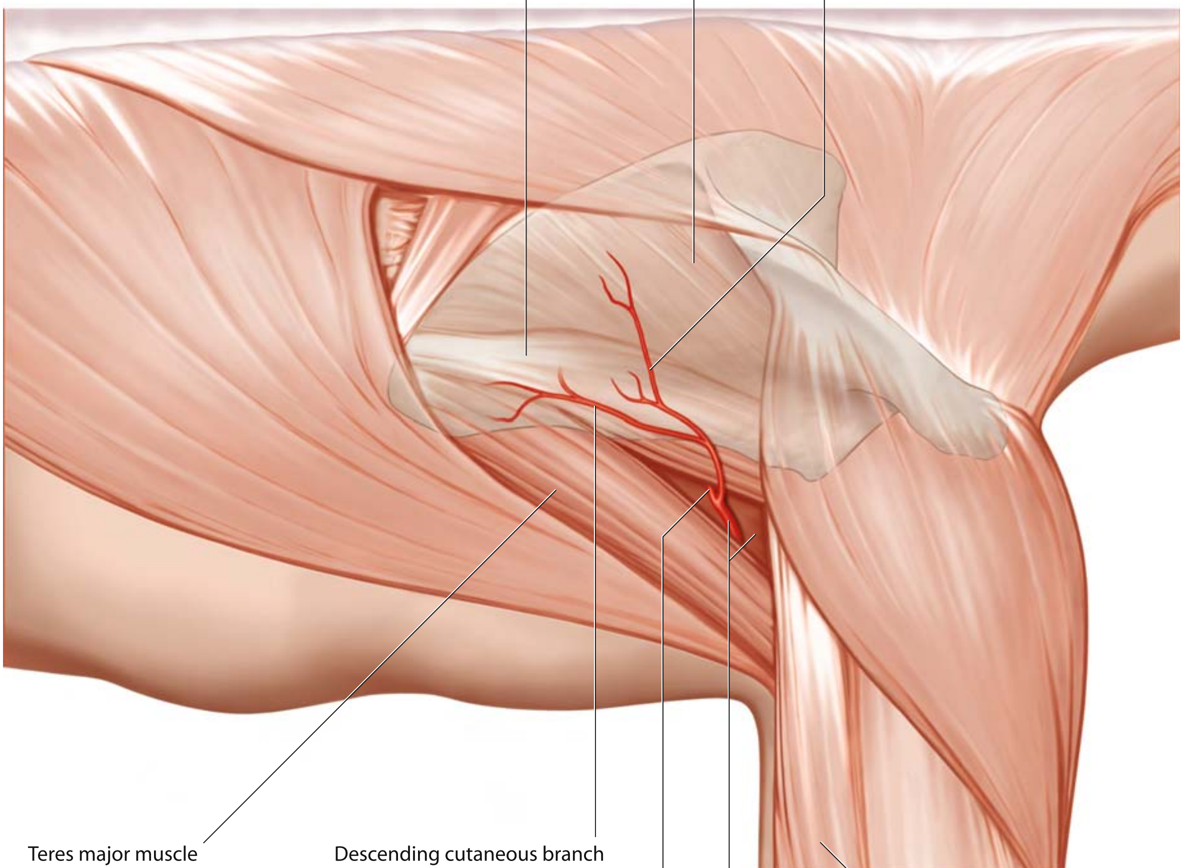
The osteotomy is performed, beginning 1–2 cm inferior of the glenohumeral joint. Here, care must be taken not to injure the vascular pedicle. The osteotomy is normally carried out 2–3 cm parallel to the lateral border of scapula and can include the whole inferior angle. Step 10

Step 11 After completion of the osteotomy, the bone segment is still attached to the subscapularis and teres minor muscles. Retracting the scapular bone segment laterally, the subscapular muscle becomes visible at the undersurface of the scapula and is divided in a distal to cranial direction.

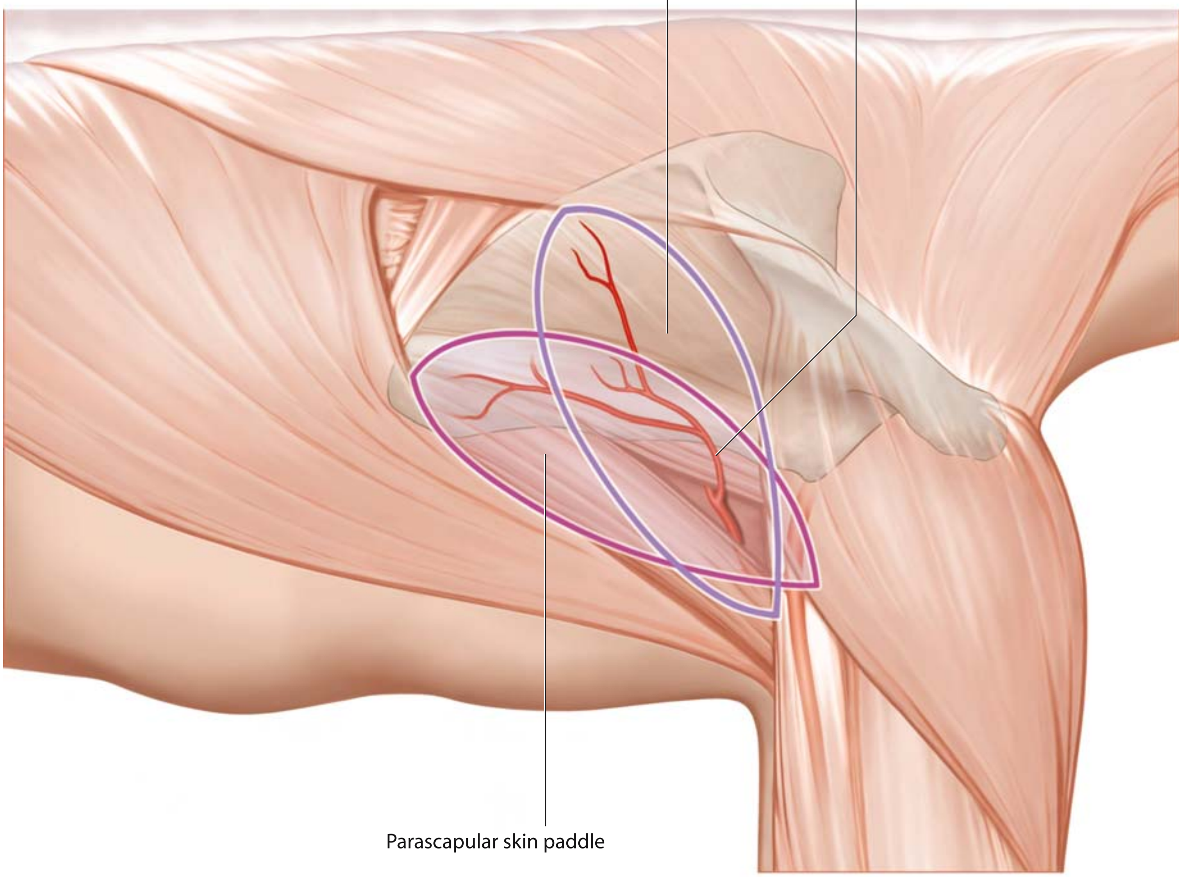
Step 12 Residual muscular attachments are identified at the vascular hilum of the bone segment, and the remaining fibers of the subscapular muscle are divided.

Step 13 The bone flap can now be further elevated, so that transection of the remaining fibers of the teres minor muscle is possible without endangering the CSA and its branches.

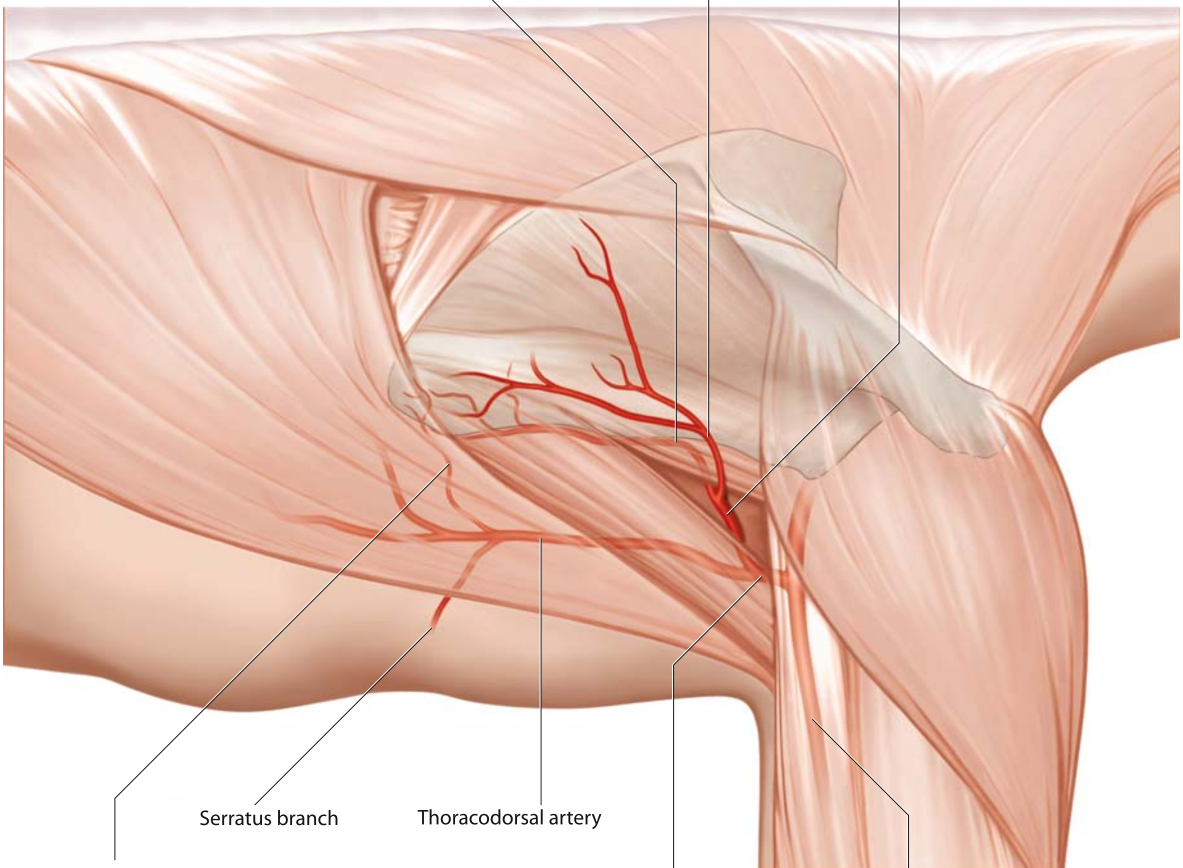
Step 14 The osteocutaneous scapular flap is now completely elevated and ready for microvascular transfer. To lengthen the vascular pedicle, the CSA can be traced to the subscapular artery. Exposure of the subscapular artery is facilitated via an additional approach through the axilla, but this is rarely necessary. To prevent winging of the scapula, the teres major muscle is reattached by drill holes in the lateral border of the residual scapula. A deep drain is inserted, and wound closure is accomplished after wide undermining. Postoperatively, the shoulder is immobilized for 1 week.



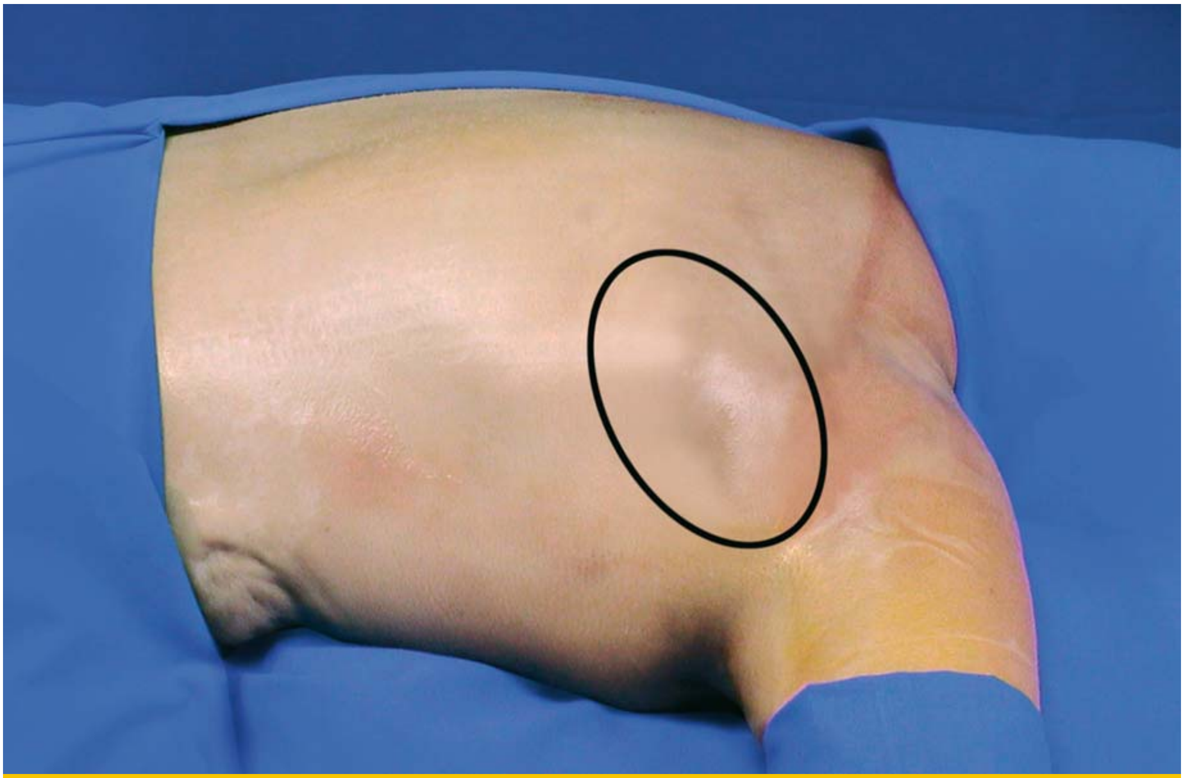
Muscle and vascular anatomy of the scapular donor site



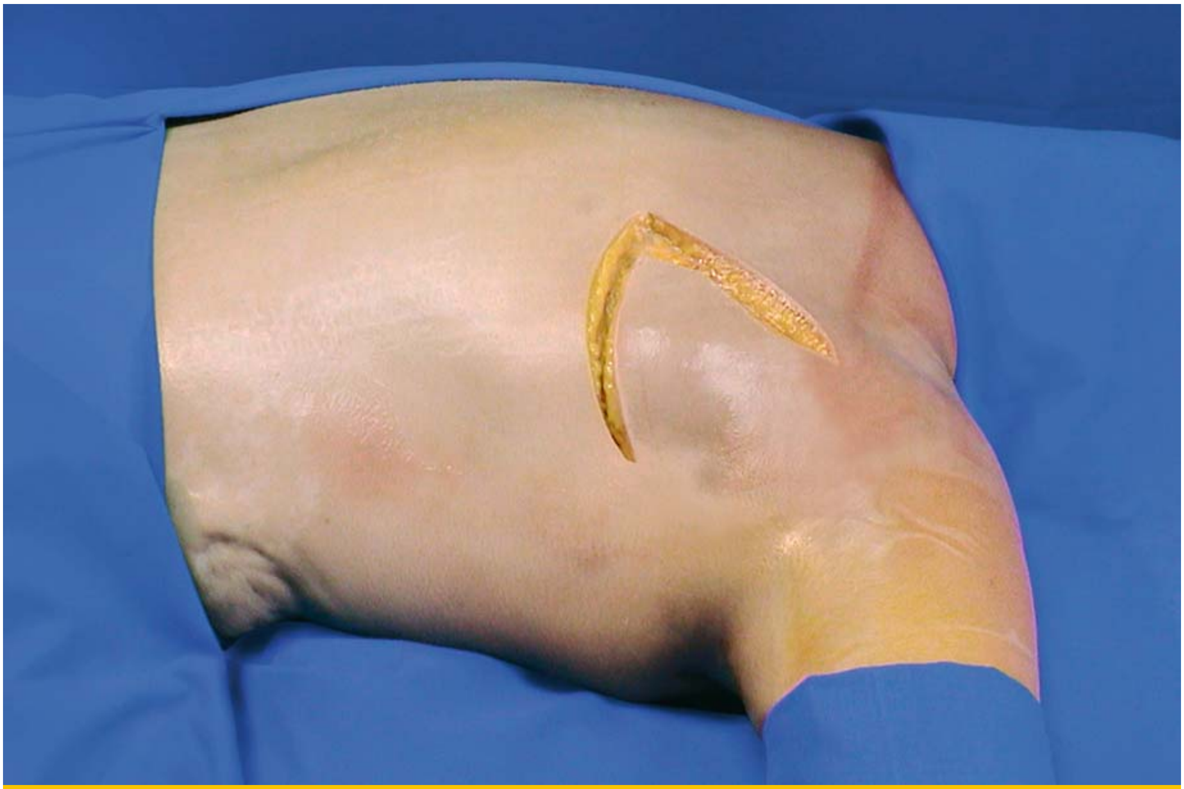
Design of scapular and parascapular skin paddle



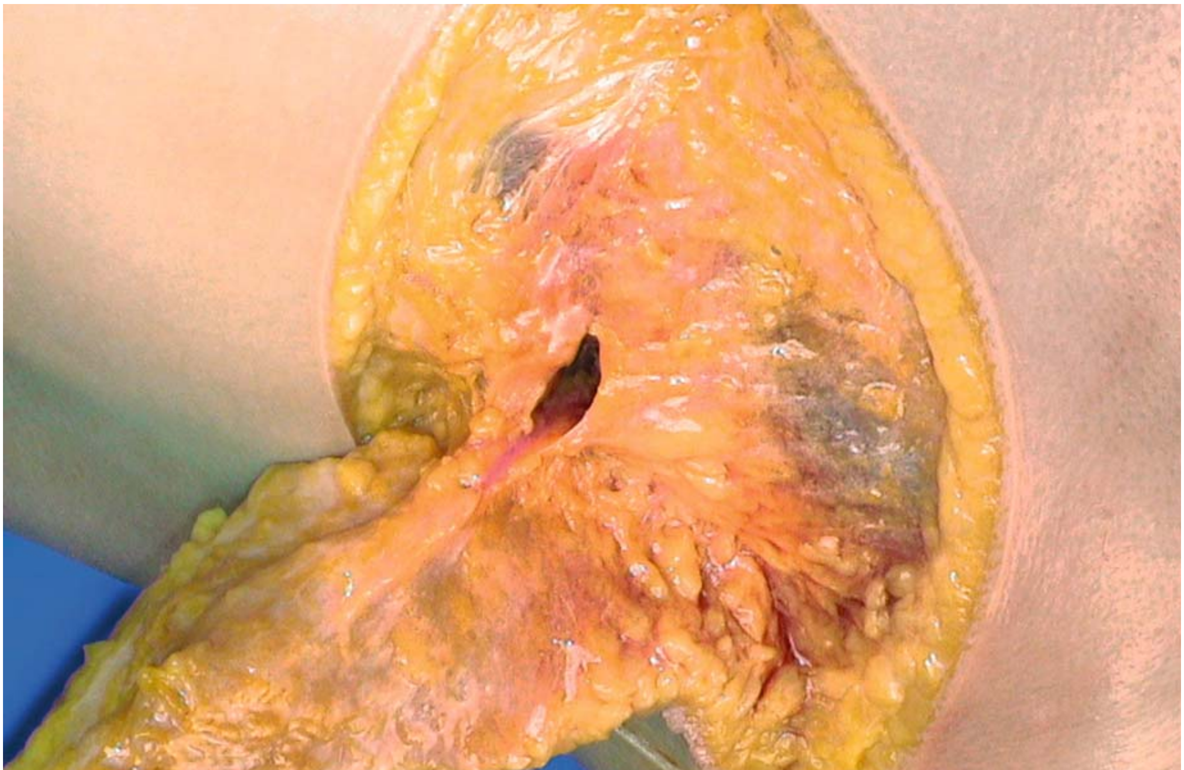
Vascular system developing from the subscapularis artery



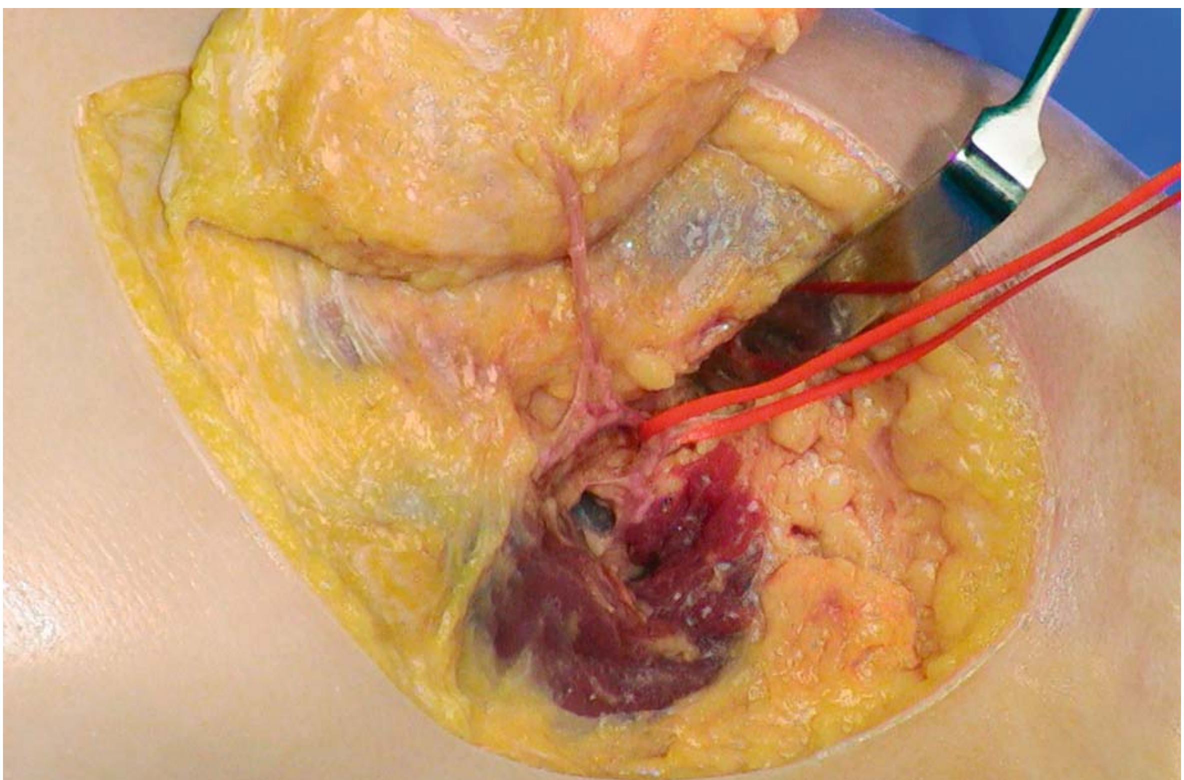
Standard design of scapular skin paddle



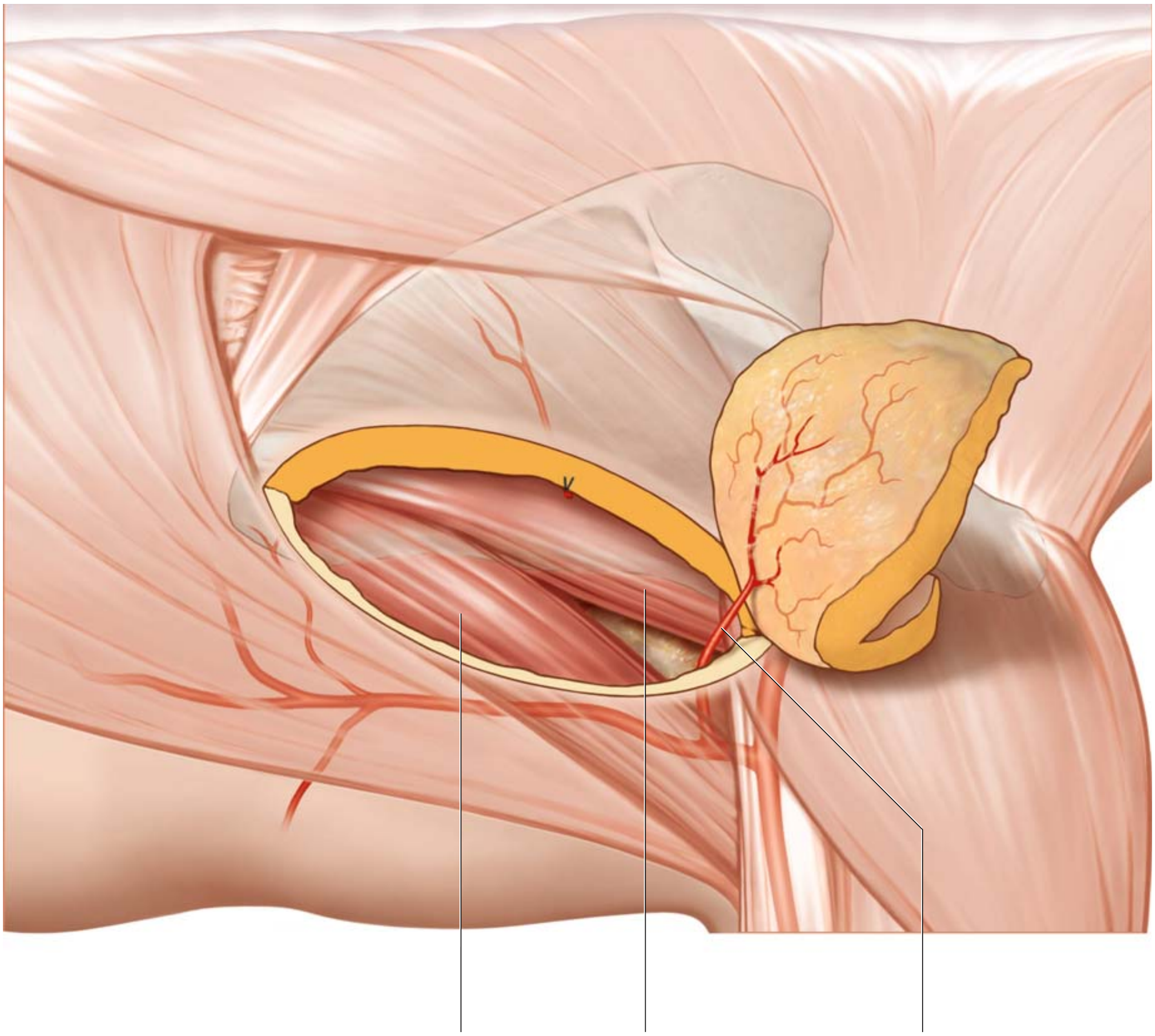
Step 1 • Circumcision of medial pole of scapular skin paddle to the deep fascia



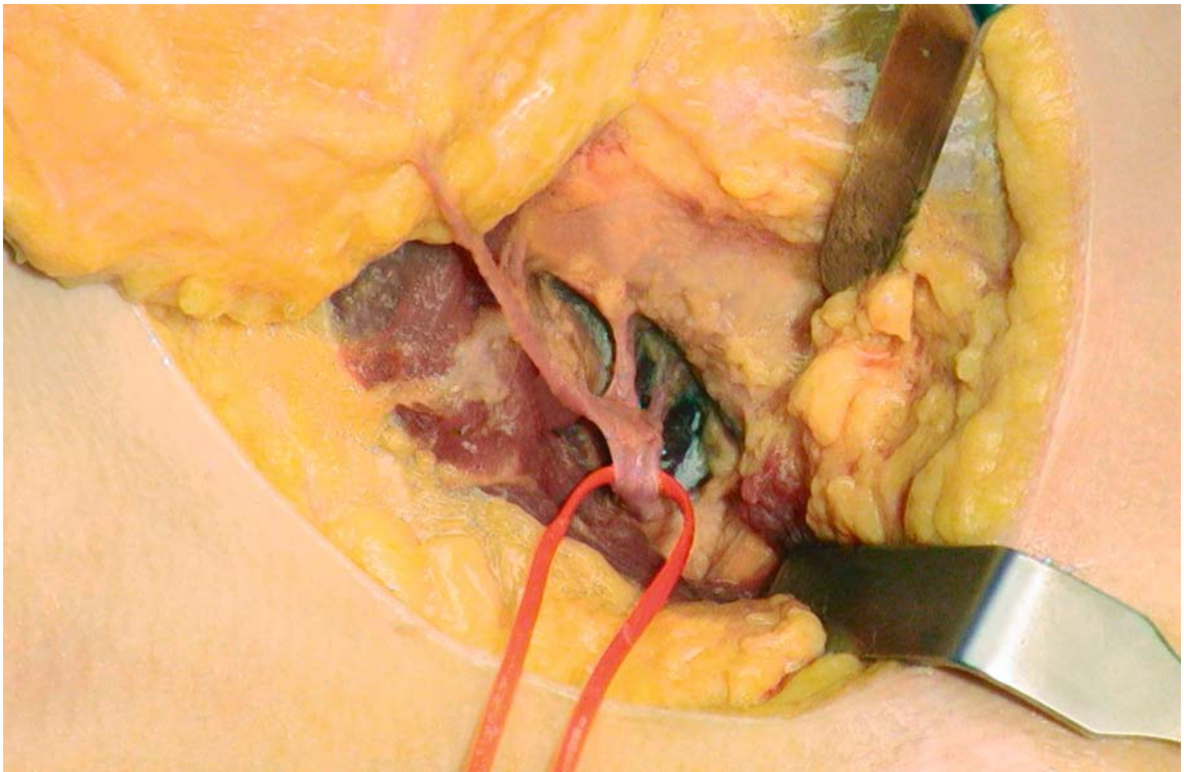
Step 2 • Identification of superficial branch of CSA



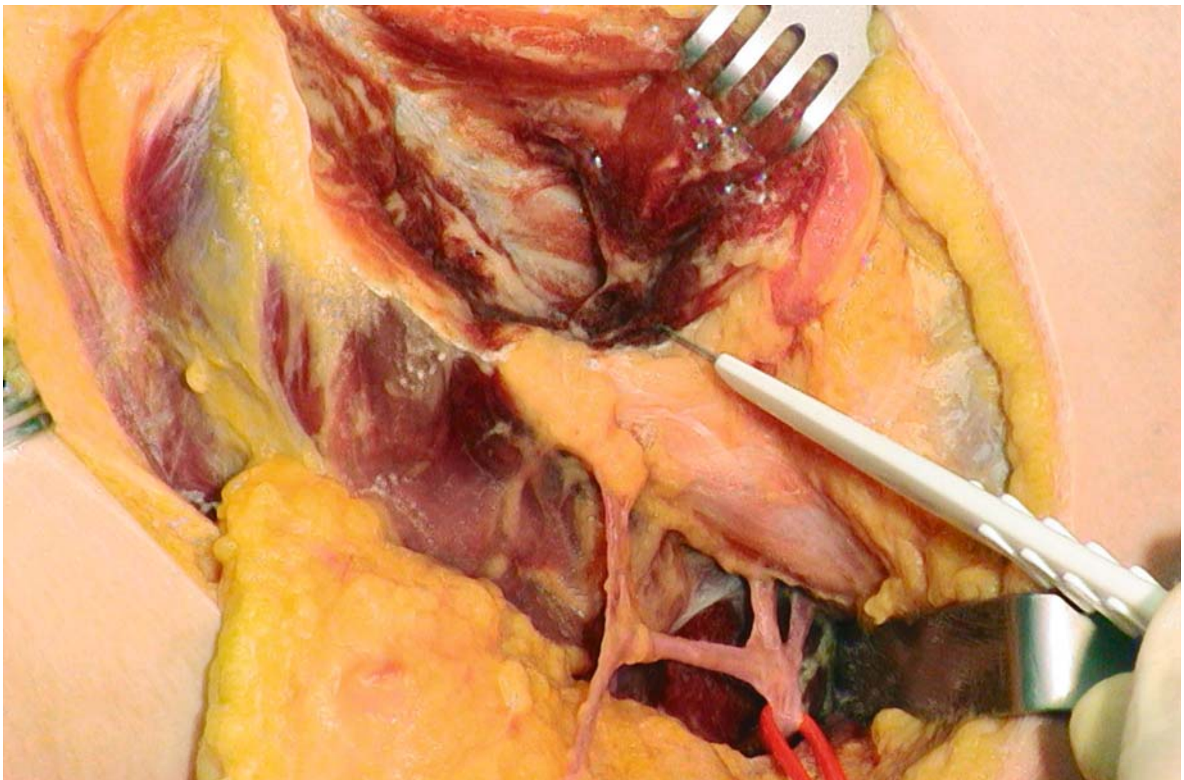
Step 3 • Dissection into triangular space, identification of deep branch of CSA



Elevation of parascapular skin paddle

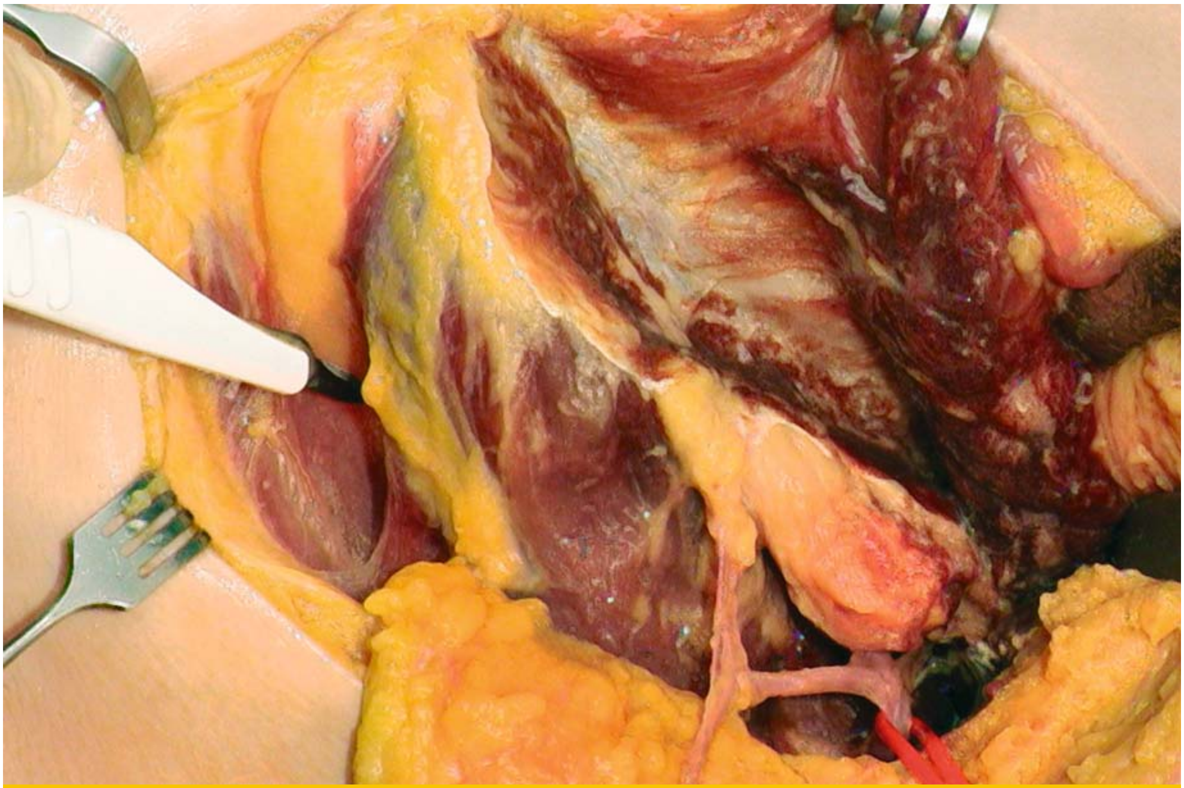


Step 4 • Identification of bone feeders

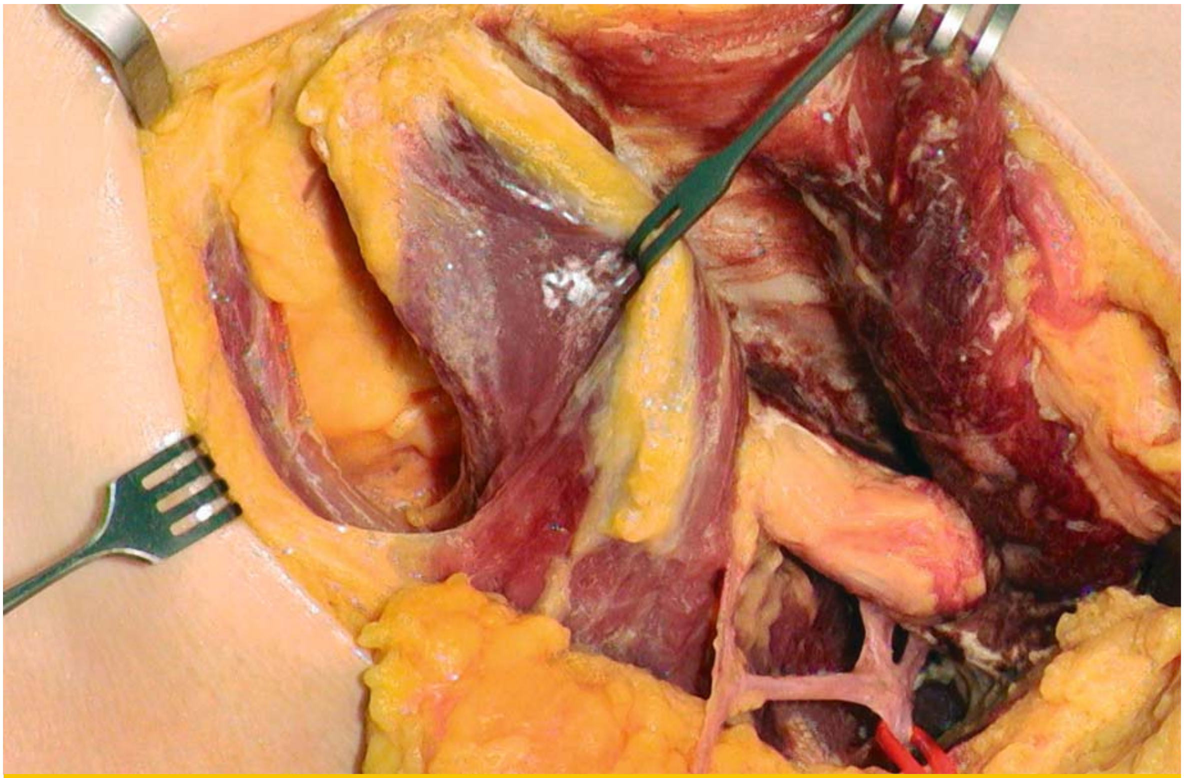


Step 5 • Incision of infraspinatus and teres minor muscles to gain access to scapular bone

Step 6 • Transection of muscle fibers cranially

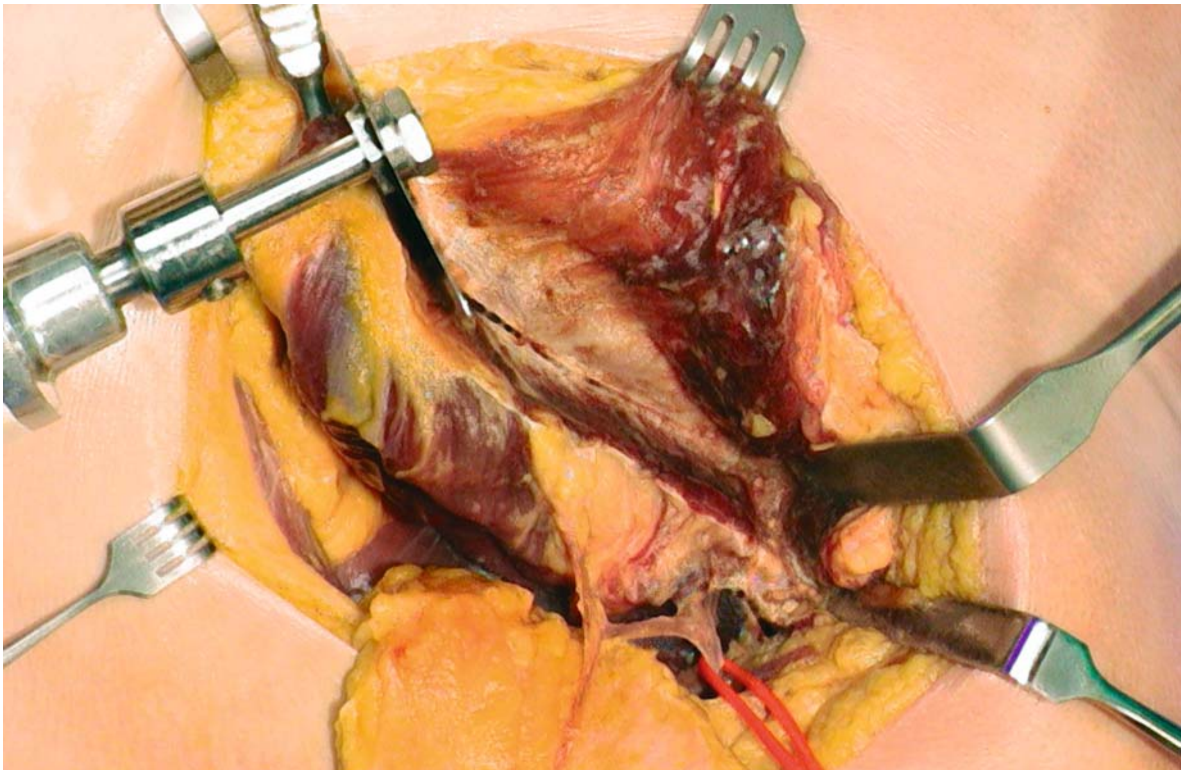


Step 7 • Undermining the inferior angle of scapula

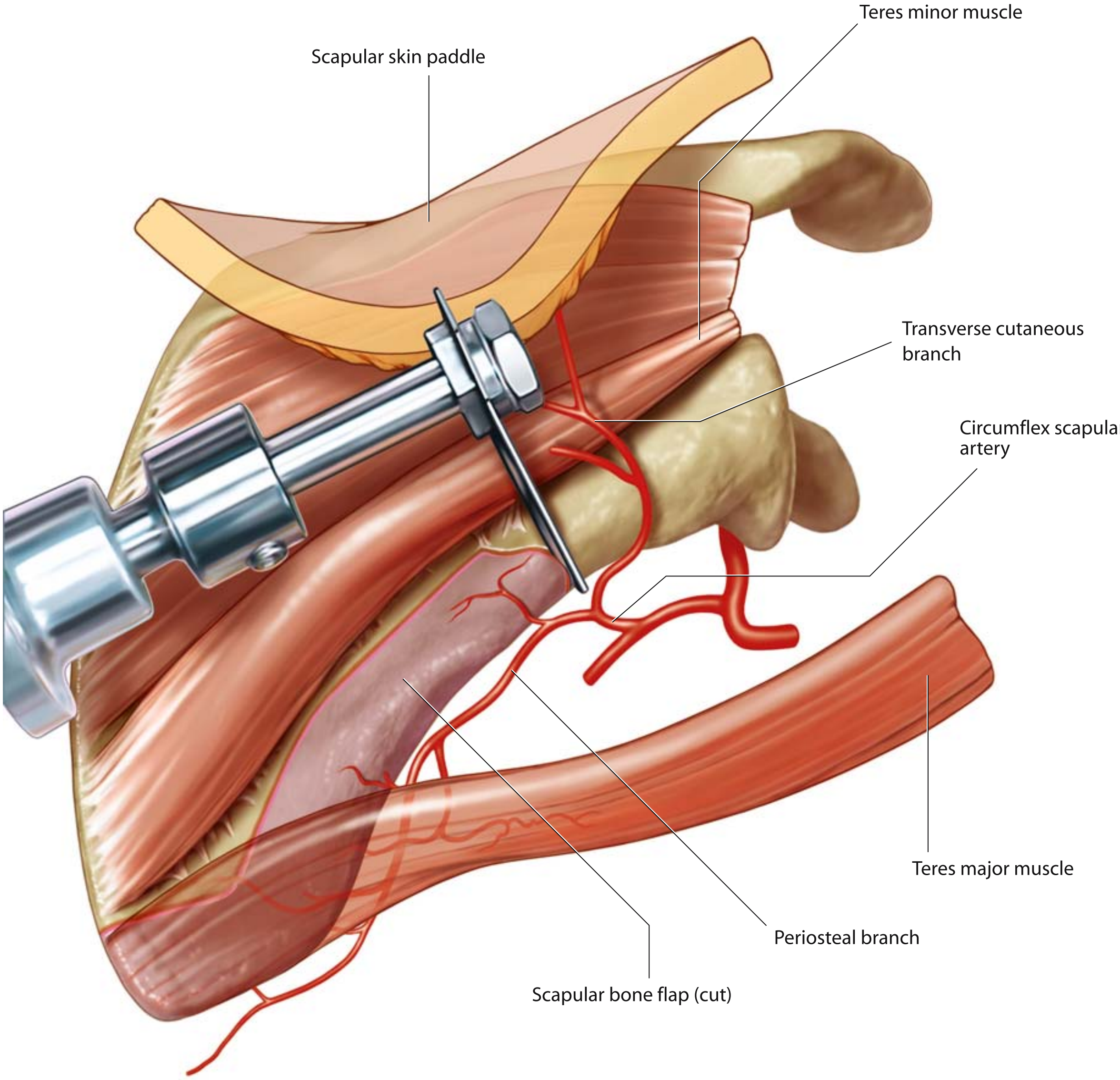


Step 8 • Undermining and elevation of teres major muscle

Step 9 • Transection of teres major at inferior angle



Step 10 • Osteotomy of scapula including inferior angle

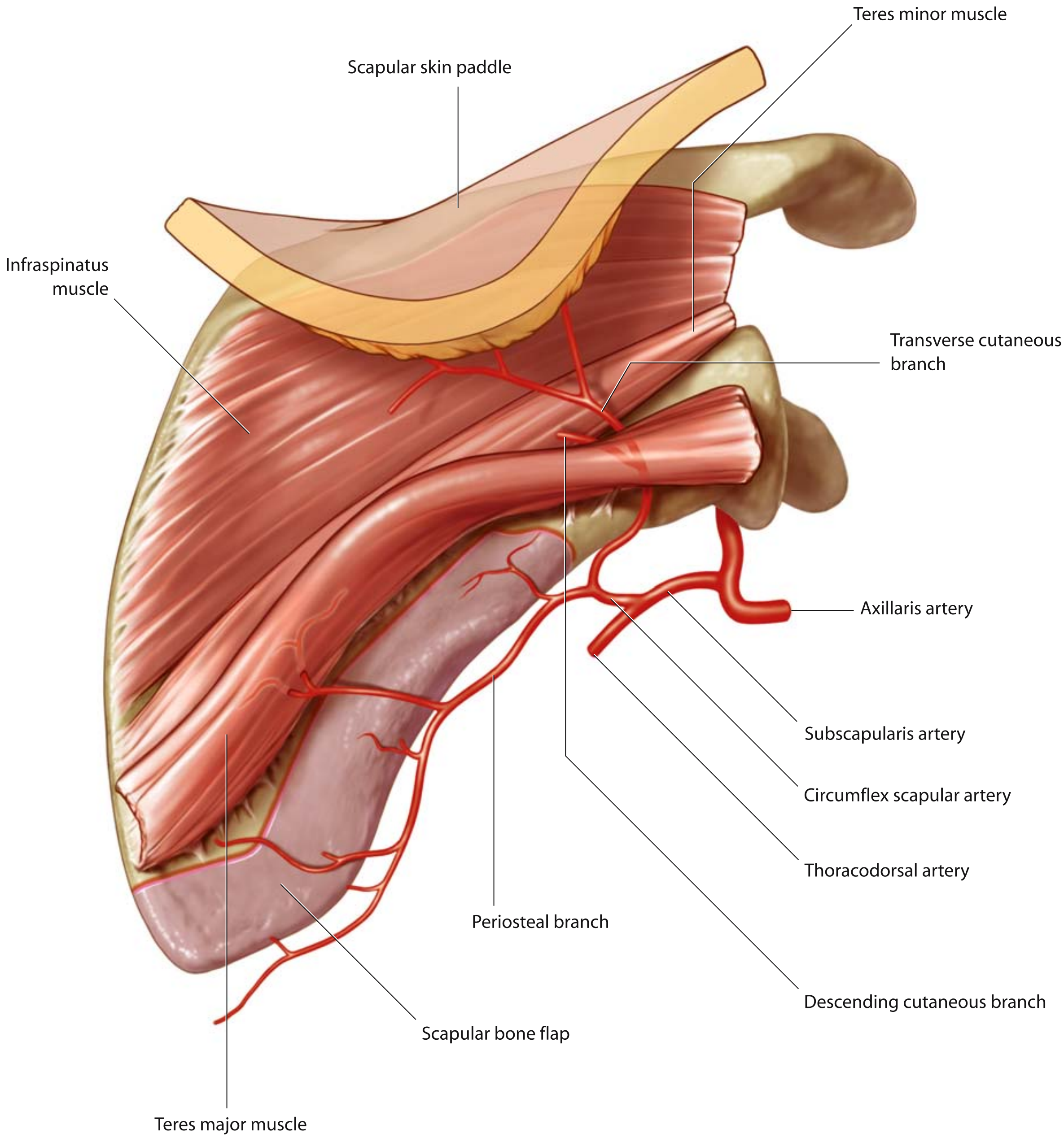


Osteotomy of lateral scapular rim and inferior angle

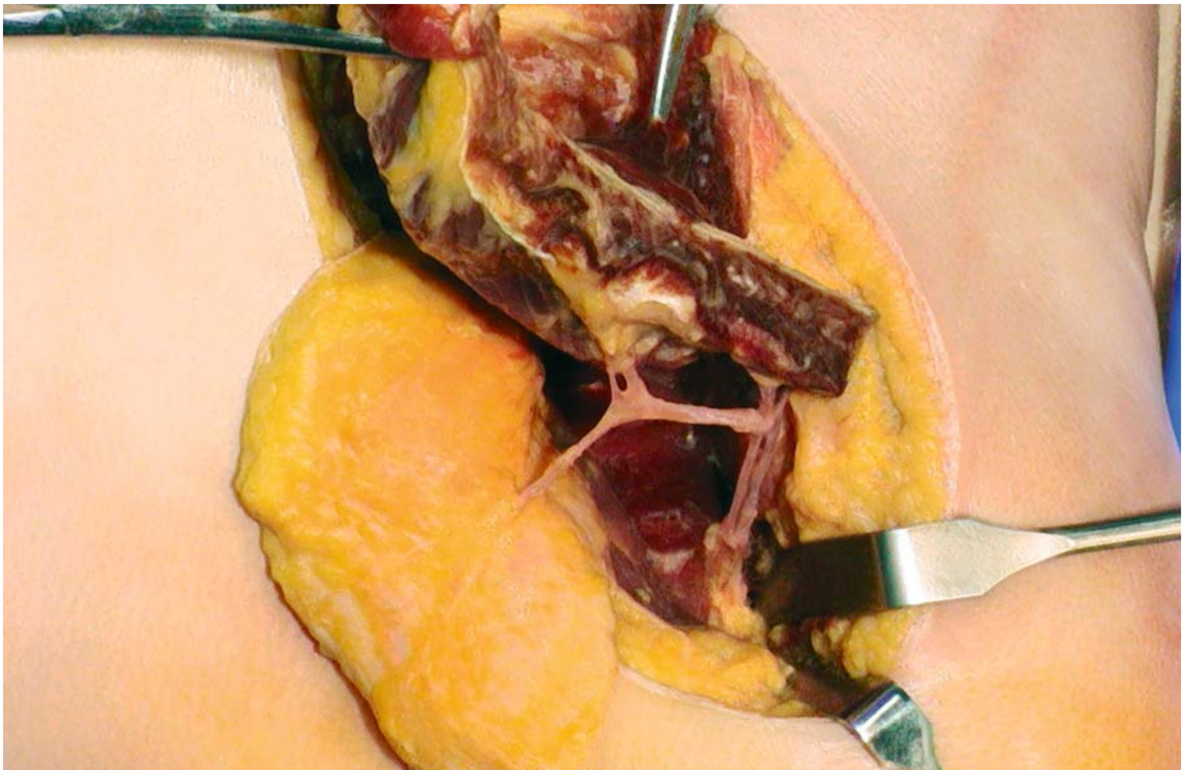
Step 11 • Division of subscapularis muscle fibers

Step 12 • Transection of subscapularis muscle fibers cranially to CSA

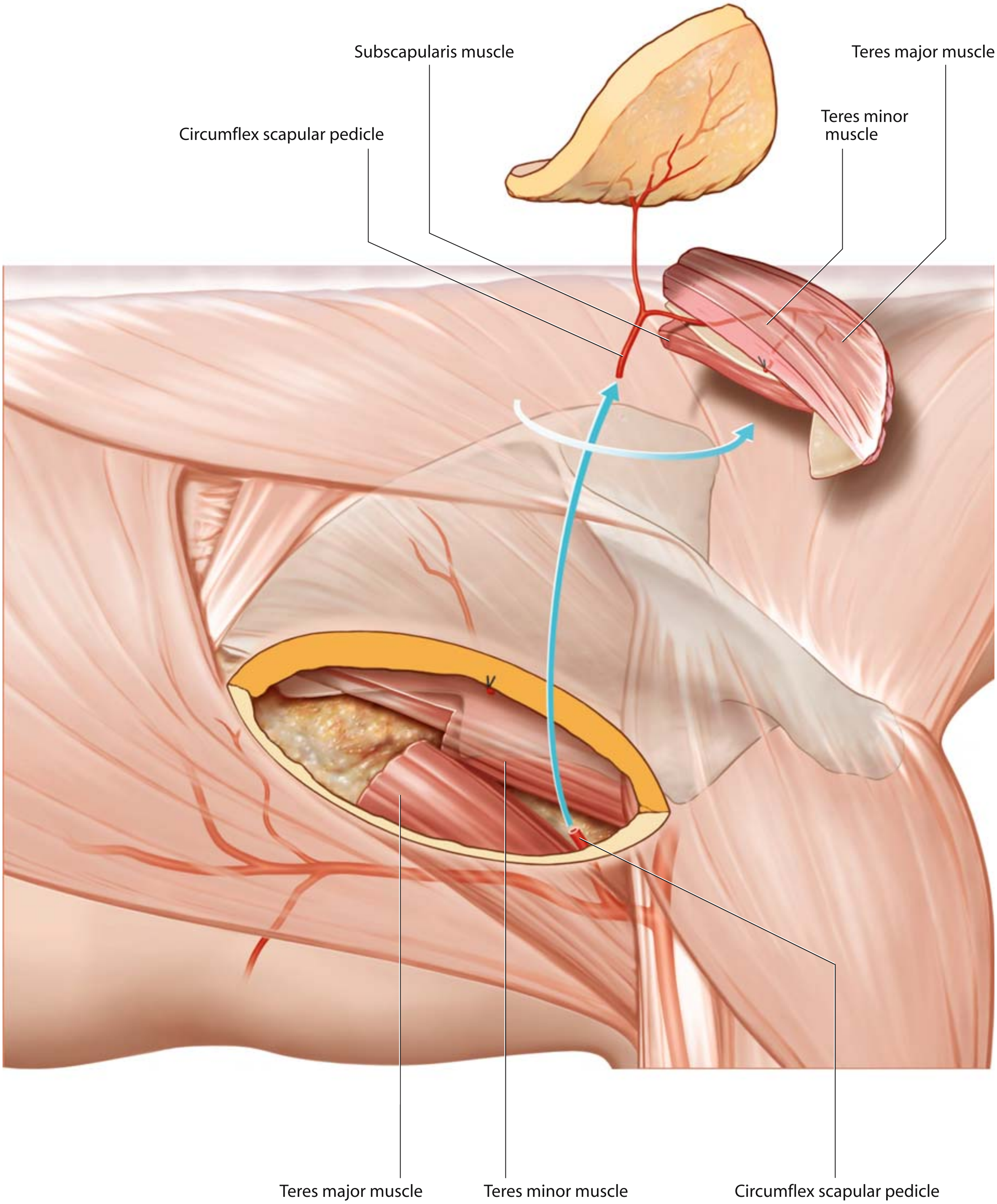
Step 13 • Transection of remaining fibers of teres minor muscle



Vascular anatomy of the osteocutaneous scapular flap



Step 14 • Complete elevation of the osteocutaneous scapular flap



Raised osteocutaneous scapular flap and donor site defect

Comments

Planning

In obese patients, palpation of the triangular space between the teres minor, major and long head of triceps muscles can be difficult. In these patients, Doppler sonography is mandatory to determine the lateral pole of the skin paddle.

Step 1: The lateral pole of the flap should not be defined until the CSA is identified.

Step 3: Many muscular branches have to be ligated during dissection of the deep segment of the CSA. To make sure that no branch to the bone is transected, the osseous feeders first have to be identified at the lateral margin of the scapula.

Steps 4–9: When preparing the scapula for the osteotomy by dividing the muscle fibers, care must be taken not to injure the CSA and its branches to the bone.

Step 8: If it is only the angle of scapula that is to be transferred, the thoracodorsal artery is chosen as the vascular pedicle instead of the CSA, because the tip of the scapula is nourished by the scapular branch of the thoracodorsal artery.

Step 10: The bone segment should not be extended too close to the glenohumeral joint, where the thickness of the scapular bone is markedly increased. Injury of the joint will lead to significant dysfunction of the shoulder.

Steps 10–13: The skin paddle, which has already been elevated, must be protected from shearing strains while handling the bone segment. The superficial branch and all branches to the scapular bone must be observed during transection of the residual adherent muscle fibers.

Step 1, 2, 14: Direct closure of the donor site under excessive tension must be avoided. If the width of the skin paddle exceeds 8–10 cm, another donor site should be considered.

Chapter 6

Fibular Flap

Development and Indications

The first microvascular bone transfer was performed by Taylor and coworkers, who used a vascularized myoosseous segment of the fibula for treatment of a post-traumatic defect of the tibia in 1975 [255]. Since this first description, the primary indications for the fibular bone flap have been reconstructions of extended bone defects in the extremities by using a posterior approach for flap harvesting.

Whereas these first transfers of the fibula were performed without including a skin paddle, Chen and Yan were the first to report an osteocutaneous fibula flap in 1983 [39]. This extension of flap raising became possible following the proposal of Gilbert to use a lateral approach for harvesting the bone flap, which was easier to perform and allowed for visualization of the cutaneous branches of the peroneal artery [82]. A valuable extension of the indicational spectrum of the fibular flap was achieved by Hidalgo, who performed the first lower-jaw reconstruction in 1989 using osteotomies to mimic the shape of nearly a whole mandible [105]. Since that time, the fibula flap has proven to be a valuable method for mandible reconstruction, especially in extensive defects exceeding the length of half a mandible [39, 74, 105, 151, 218, 228, 277, 287]. By inclusion of the soleus muscle, which then was connected to motor branches at the recipient site, restoration of motor function was achieved [44]. Because of the bone length and the potential to vary the position of the skin paddle, it is possible to combine bone segments and skin islands from different parts of the flap, allowing more flexibility in flap design [278, 286, 287]. Moreover, two separate skin paddles can be harvested and used for closure of perforating defects of the cheek, simultaneously reconstructing the mandible using fibular bone [74, 105, 278, 287]. To overcome the limited height of the fibula, Jones introduced the possibility of folding two osteotomized bone segments over themselves [123]. This "double-barreled" fibular flap was first used for reconstruction of segmental defects of the femur until this method was adapted to mandible reconstruction. To restore sensation of the skin paddle, Hayden and O'Leary harvested the sural cutaneous nerve together with the skin island and anastomosed this nerve to sensory nerves of the oral cavity [103]. Sensate fibular flaps were later also used for penile reconstruction [213]. Flap combinations were performed by anastomosing a second free flap to the distal peroneal artery and vein, which do not reduce the caliber significantly and thus additionally can serve as "donor vessels" at the recipient site [277].

Anatomy

The dominant vascular pedicle of the fibular flap is the peroneal artery, which develops from the posterior tibial artery. Together with the tibial anterior artery, it represents one of the three main branches of the popliteal artery. Accompanied by two veins, the lateral of which is usually larger [93], the peroneal artery travels distally between the flexor hallucis longus and tibialis posterior muscles and, besides its muscular branches, gives off several periosteal and medullary branches to the fibula bone, as well as a number of cutaneous perforators, running along the posterior intermuscular septum to the skin of the lateral calf. Normally, the peroneal artery does not contribute to the blood supply of the foot significantly, but owing to a number of anatomical variations concerning the tibial anterior or posterior vessels, the peroneal artery can become a dominant nutrient vessel to the foot. According to the anatomical literature, the tibial anterior and posterior vessels can only be rudimentally present or completely missing [4, 78, 80, 88, 104, 112, 114,119, 145, 193], so preoperative angiography or magnetic resonance tomography must be performed to evaluate the vascular anatomy of the donor site [255, 286, 287, 295]. If one of the three main arteries is significantly reduced in caliber or missing, no flap raising should be performed in this leg. Additionally, atherosclerotic changes will lead to an increased risk for flap loss, and long-term ischemic complications at the donor site are possible, so in these cases another donor site should be considered. Although the venous anatomy has been found to be unique in every individual, no contraindications have been found from a venous standpoint to raising fibular flaps. The two venae comitantes do not necessarily coalesce into a single common peroneal vein, but they do in 66 % and then can be lengthened up to the confluence with the popliteal vein. Nevertheless, because of some anatomical exceptions, the choice of donor vein and venous pedicle length should depend on the anatomy encountered intraoperatively [93].

Although the fibular bone is nonweight-bearing, 7–8 cm segments must be preserved at the proximal and distal ends during flap raising to protect the common peroneal nerve at the fibular neck and prevent instability of the ankle. Despite these limitations, up to 25 cm of bone length can be harvested, which is enough to restore subtotal or even total mandibular defects [82, 105]. For osteocutaneous transfer of the fibular flap, the location and course of the cutaneous perforators are of particular interest. According to clinical experience and anatomical studies that have been performed to evaluate the reliability of the blood supply to the skin, the cutaneous perforators of the peroneal artery vary in location, course, size, and number. Thus, different survival rates of the skin paddle have been reported and various proposals have been made to improve the reliability of the fibular flap skin island. Hidalgo, who performed five osteocutaneous fibular transfers in his first series of 12 patients, reported four complete or partial losses and only one complete survival of the skin paddle [105]. To increase the number of cutaneous perforators and thus the safety of skin perfusion, he therefore suggested that the whole posterior intermuscular septum always be included, despite the size of the skin paddle [106]. Because of the anatomical variations of the perforating vessels, Urken considered loss rates between 7 and 10 % to be inevitable [272]. In an anatomical study on 52 cadavers, Chen et al. found 4–7 cutaneous branches, most of them having a myocutaneous course and perforating the soleus muscle [39]. Another description of the cutaneous arteries was given by

Yoshimura et al., who differentiated myocutaneous perforators, traveling through the peroneal muscles, septomyocutaneous perforators, running between the peroneus and soleus muscles and giving off further muscular branches, and purely septocutaneous vessels [296]. A different classification was proposed by Wei and coworkers, who only made a distinction between septocutaneous perforators traversing the whole intermuscular posterior septum, and musculocutaneous perforators, additionally coursing through either the peroneus, tibialis posterior, or soleus muscle [277]. In a later publication, these authors reported a 100% survival rate of the skin paddle in more than 100 patients by centering the skin paddle over the transition of the middle and distal third of the fibula [278]. In contrast to the findings of Wei, Carriquiry was only able to identify septocutaneous perforators in their ten anatomical dissections [32]; this was supported by Carr and coworkers [31], who stated that the cutaneous perfusion is maintained exclusively by septocutaneous vessels. In an extensive anatomical dissection on 80 cadavers and supported by their clinical experience in 18 patients, Schusterman et al. found 3.7 cutaneous perforating vessels from the peroneal artery on average, 1.3 of these having a septocutaneous, 1.9 a myocutaneous course, and 0.6 showing direct adhesion to the muscle fascia without penetrating the muscles [225]. Because of this variability, the authors proposed that a cuff of tibialis posterior and soleus muscle should always be included on either side of the septum for safety reasons. A similar suggestion was also made in 1986 by Harrison, who improved his success rate with the skin paddle using this method [99]. Despite this, Van Twisk considered the inclusion of a muscle cuff to be necessary only if no septocutaneous vessels could be visualized [266]. Yoshimura gave the first description of the peroneal flap [296], which is nourished by the same cutaneous vessels as the osteocutaneous fibula flap. In his anatomical study on 80 cadavers he found 4.8 cutaneous vessels on average, 71% of them having a myocutaneous course to the skin [296]. Although he believed that the skin paddle should be designed at the junction of the middle and distal third of the fibula, other authors have proposed centering the flap 2 cm superior to the midpoint between the fibular head and ankle [39, 153, 223, 248]. According to Flemming et al., exposure of the cutaneous vessel is best performed by an anterior and subfascial incision [74]. If no septocutaneous vessels are identified, part of the soleus muscle must be included to capture the myocutaneous perforators [74]. In an anatomical study by Wolff, 4.2 cutaneous perforators were found, most of them having a myocutaneous course through the tibialis posterior and soleus muscles at the proximal and a septocutaneous course at the distal lower leg [286]. The most reliable region to build a skin paddle turned out to be 8–12 cm proximal to the ankle, because here a strong perforator, mostly having a septocutaneous pattern, was found in all 50 of the cadavers. As a result of these anatomical findings, the author proposed that the skin paddle be routinely designed at the junction between the middle and distal third of the fibula, additionally offering the possibility to dissect a long vascular pedicle. Depending on the length of bone segment needed and the level on which the peroneal artery unifies with the tibial posterior vessels, the vascular pedicle can reach up to 15 cm if the skin paddle is raised distally [283, 286, 287]. To obtain a long pedicle, Hidalgo proposed removing the longest fibular segment possible and then discharging the proximal bone segment after dissecting the pedicle together with the surrounding soft tissues in a subperiosteal plane [107]. The blood supply to the distal fibular segment is not altered by this maneuver. Dye injections have been carried out to determine the territory of skin available for the osteocutaneous fibula transfer. When injecting proximally into the peroneal artery, a skin territory about 10 cm in width and 20 cm in length is stained, allowing nearly the entire skin of the lateral calf to be transferred. Raising such a large skin paddle was always considered problematic because of the extensive donor-site skin defect. Therefore, other authors proposed that large skin flaps be raised from an additional donor site or that another osteocutaneous flap be used [151, 278]. Selective injection studies have shown that a skin territory of about 12×7 cm can be safely perfused by one single perforating vessel [283], giving the anatomical basis to build two separate skin paddles not only by de-epithelialization [74], but also by complete transection of the flap between the two perforators. To facilitate identification of the perforators, preoperative mapping using audible Doppler sonography is strongly advisable. Direct closure of the skin is achieved up to a flap width of 6–7 cm in the upper and middle third of the lower leg, whereas distally, skin grafts have to be used for wound coverage in most cases. After flap raising, the patient is immobilized for 3–4 days and then allowed to walk with physiotherapeutic assistance.

Advantages and Disadvantages

The fibula is the longest bone flap available and can be transferred as a bone flap or in combination with one or two skin paddles. Its indicational spectrum therefore reaches from bony reconstruction in the extremities to replacement of the whole mandible, including closure of large perforating defects of the oral cavity. Flap raising can be carried out using the two-team approach, making this donor site attractive especially for primary reconstructions in the head and neck area. The quality of the thin and pliable skin paddle is comparable to the radial forearm skin, and the 3–5 cm broad septum provides good flexibility to the skin island, which can be brought into the oral cavity for lining without tension. Thus, the osteocutaneous fibular flap is perfectly suitable for reconstruction of composite defects of the mandible. The flap possesses a sufficient long and high-caliber vascular pedicle, making microsurgical anastomoses easy to perform. Although the vertical dimension of the fibula is limited to half of a toothed mandible, enosseous dental implants can be regularly inserted, with high primary stability because of the high amount of cortical bone. The limited height of the fibula is not a problem in patients who already have some degree of atrophy of the alveolar process because there is not much difference in height between the fibula and the atrophied mandible. In nonatrophied toothed mandibles, the application of a double fibular transplant has been suggested to compensate for the narrowness of the transplant and create better conditions for prosthetic management [123]. However, the majority of authors have shown that prosthetic rehabilitation is also possible without using a double transplant [107, 118, 151, 278]. Nevertheless, thinning of the skin flap around the implant is always necessary before prosthetic rehabilitation can be performed. Despite the numerous advantages attributed to skin quality, bone length, and vascular pedicle, for isolated bone defects of the mandible not exceeding the midline, the iliac crest should be preferred owing to the fact that it mimics the natural shape of the lower jaw better.

The frequency of arteriosclerotic changes in the lower leg vessels is a well-known clinical fact and must be taken into consideration in the choice of flaps. Although some authors [60, 107, 154] consider routine angiography in cases of clinically normal foot-pulse findings unjustified, the majority assess the donor-site vascular anatomy and the status of the vascular integrity by preoperative measures like angiography or magnetic resonance tomography [149, 161, 255, 287, 295]. Clinical experience indicates that one out of five candidates has to be excluded from a fibular transfer because of severe arteriosclerotic damage or venous insufficiency of the lower-leg vessels [287]. The unreliability of the skin supply has been another criticism of the osteocutaneous fibular transplant and is the reason why numerous studies have reported it to have several disadvantages, in particular, the variability of the cutaneous perforating vessels and the limited size of the skin island [31, 74, 105; 107, 118, 225, 278, 296]. According to the reports by Hidalgo [106] and Schusterman [225], loss of the skin island must be considered in 7–9 % of the cases. On the basis of anatomical studies and the clinical experience of other authors [123, 273, 277, 278, 283, 286, 287], the transition of the middle and distal third of the fibula represents a reliable donor site for the fibular skin paddle, which at this location is supplied by septocutaneous peroneal perforators. Having a survival rate of at least 95 %, the safety of this skin paddle does not differ from other proven transplants [123, 273, 278, 287]. The possibility of forming two isolated skin islands, as already demonstrated by Yoshimura, extends its indicational spectrum [297]. Nevertheless, Yakoo and coworkers pointed out that the perforator of the skin paddle as a variation can branch off from the tibialis posterior instead of from the peroneal vessels [295]. In these cases, it is necessary to anastomose the perforating vessel directly or, if no other peroneal cutaneous perforator is available, to use a second skin flap. Neurocutaneous reinnervation by connecting the sural nerve, as suggested by Sadove et al. [213] and Wei et al. [278], is not an absolute requirement for sensory innervation of the flap; instead, it seems that, in at least some cases, there is spontaneous neurocutaneous reinnervation owing to the sprouting of sensory fibers from the periphery.

Some authors report the length of the vascular pedicle as ranging from 4 to a maximum of 8 cm so that in many of their cases vein grafts were necessary [74, 151, 266]. The dissectable vascular pedicle length is, however, much longer if the transplant is raised from the distal third of the lower leg where not only the skin supply is more reliable via septocutaneous perforating vessels, but where the fibula is better perfused via periostal branches [286]. Vein grafts may only become necessary if long bone segments are required for subtotal mandible reconstruction because in these cases, proximal lengthening by separation from the fibula is only possible to a limited extent. A short vascular pedicle can also result if the exit of the peroneal artery lies more distally, which can, however, be recognized preoperatively by angiography.

According to reports in the literature, donor-site morbidity of the fibular flap is generally low. Apart from hypoesthesia at the lateral malleolus, slight initial pain and a tendency towards edema can be found, and the flexing or stretching function of the large toe or ankle joint is objectively reduced but this is hardly noticeable subjectively [51, 86, 107]. Nevertheless, some patients report pain and weakness on ambulation for several months after surgery [22, 172, 273], and a lower preferred velocity on walking is found compared with control subjects [22]. Instability of the ankle joint has not been found in any of the patients [51, 146]. The development of radiological signs of osteoporosis can occur in the distal fibula segment after several years, but it does not lead to any disability on ambulation or change the shape of the ankle joint [146]. Hematomas can occur as a result of oozing from the resection margins of the bone at the donor site, and care must be taken to prevent the development of a compartment syndrome [52]. Primary closure of the donor-site defect should only be undertaken if this can be accomplished with no tension because, according to a study by Shindo et al., primary closure otherwise bears a higher complication rate than split-thickness skin grafting [234]. In order to ensure optimal healing of split-thickness skin grafts, a tie-over dressing should be applied and the lower leg should be immobilized for about 3–4 days.

Flap Raising

Preoperative Management

Owing to possible variations of the tibial posterior and anterior vessels and the prevalence of arteriosclerotic damage in the lower extremities, conventional angiography or, which is less invasive, magnetic resonance angiography is mandatory before raising the fibula flap. Patients showing clinical signs of vascular damage (varicosis, missing foot pulses, pain on ambulation) should primarily be excluded. Marking the cutaneous perforators along the posterior intermuscular septum using Doppler sonography facilitates intraoperative exposure of these vessels.

Patient Positioning

The leg is bent at the knee joint and brought into a prone position to obtain better access to the lateral and posterior aspect of the calf. This is facilitated by supporting the hip with a beanbag. The entire lower extremity is prepped circumferentially, and the foot is draped, leaving the pulses accessible. No tourniquet is used because identification of the pulsating perforators is easier in the perfused leg. With consistent hemostasis and careful dissection, flap raising is possible without any significant bleeding, and the risk for diffuse oozing after release of the tourniquet and postopartive hematoma formation (compartment syndrome) is reduced.

Flap Design

Despite the fact that mapping of the perforators and thus positioning of the skin island is possible preoperatively using Doppler sonography, the skin paddle should not be designed until the cutaneous branches are clearly seen intraoperatively. In the standard situation, the skin paddle is centered vertically along the septum with its center at the junction between the middle and lower third of the fibula. If only one perforator is enclosed, the flap size should not exceed 6 × 10 cm. A distance of 8 cm from the lower osteotomy to the ankle must be kept for stability of the malleolar joint; proximally, a 7 cm bone segment is maintained to protect the peroneal nerve.

Flap Raising

Step 1

An incision is made in the skin along the peroneus longus muscle, keeping a distance of 2 cm from the posterior intermuscular septum, which easily can be palpated posterior to the muscle. According to the location of the perforator found by preoperative mapping, the incision is slightly curved anteriorly in the region of the skin paddle. The strong crural fascia is incised according to the skin incision.

Step 2

The perforator is visualized by carefully separating the fascia from the peroneal muscles and blunt dissection in the posterior direction. The posterior intermuscular septum, which covers the perforator from both sides is exposed and must always be left intact in the region of the osteocutaneous flap. Once the perforator is identified, the peroneal muscles are retracted anteriorly, and the lateral margin of fibula is palpated.

Step 3

Proximal to the skin paddle, the posterior intermuscular septum is incised sharply along the lateral margin of the fibula. To obtain better access to the deep flexor space, the peroneal muscles are retracted anteriorly, and the soleus muscle is retracted posteriorly using sharp hooks.

Dorsal to the fibula bone, the flexor hallucis longus muscle becomes visible.

Step 4

The strong attachment of the soleus and flexor hallucis muscle to the fibula is divided carefully with scissors proximal to the skin paddle. Care must be taken not to enter the deep flexor space too deeply where the peroneal vessel are located.

Step 5

After transecting the attachment of the flexor hallucis longus muscle to the fibula and opening the deep flexor space, the muscles can be retracted easily, and muscular branches of the peroneal vessels are exposed.

Step 6

Continuing the dissection into the deep flexor space and tracing the muscular branches in a proximal direction, the peroneal vessels are identified. Dissection must be performed carefully to prevent any bleeding from the peroneal vessels. In the perfused leg, the artery can easily be palpated at the posterior aspect of the fibula. A number of small vessels branch off from the peroneal artery, traveling to the surrounding muscles and the fibular bone.

Step 7

A vessel loop is placed around the peroneal vessels, and the branches to the surrounding muscles and the fibular bone are clipped and transected. Perfusion of the distal bone segment is maintained and remains reliable despite sacrifice of the proximal bone feeders. Dissection of the pedicle is facilitated by complete relaxation of the patient and plantar flexion of the foot to reduce tension of the flexor muscles.

Step 8

The peroneal muscles are retracted anteriorly, leaving a small cuff of muscle around the perforator, and a curved raspatory is positioned subperiostally around the fibula to protect the distal peroneal vessels. The distal osteotomy is now performed with an oscillating saw, keeping a distance of 8 cm to the ankle.

Step 9

The proximal osteotomy is carried out in the same fashion. The longer the bone segment built for reconstruction, the shorter the vascular pedicle. In the standard situation, at least 10 cm of pedicle length is obtained using this technique.

Step 10

The anterior intermuscular septum is incised between the two osteotomies directly at the anterior rim of the fibula. The periosteum is left untouched along the whole length of the bone segment.

Step 11

The extensor muscles are bluntly separated from the fibular bone epiperiosteally until the interosseus membrane is reached. The tibial anterior vessels are located medially underneath the extensor muscles and should not be exposed.

The interosseous membrane is completely divided, keeping a distance of 1 cm to the fibula, and the fibers of the tibialis posterior muscle become visible. Minor bleeding originating from muscular perforators of the peroneal vessels is carefully cauterized. Step 12

After dividing the interosseous membrane completely, the bone segment can be retracted laterally, and the peroneal vessels are exposed by bluntly separating the fibers of the tibialis posterior muscle at the distal osteotomy. The vessels are ligated and transected distally. Step 13

The tibialis posterior muscle is divided where the V-like fibers meet at the midline, so that a cuff of muscle is left attached to the fibular bone segment. The flexor hallucis longus muscle and the posterior intermuscular septum are still left untouched. Step 14

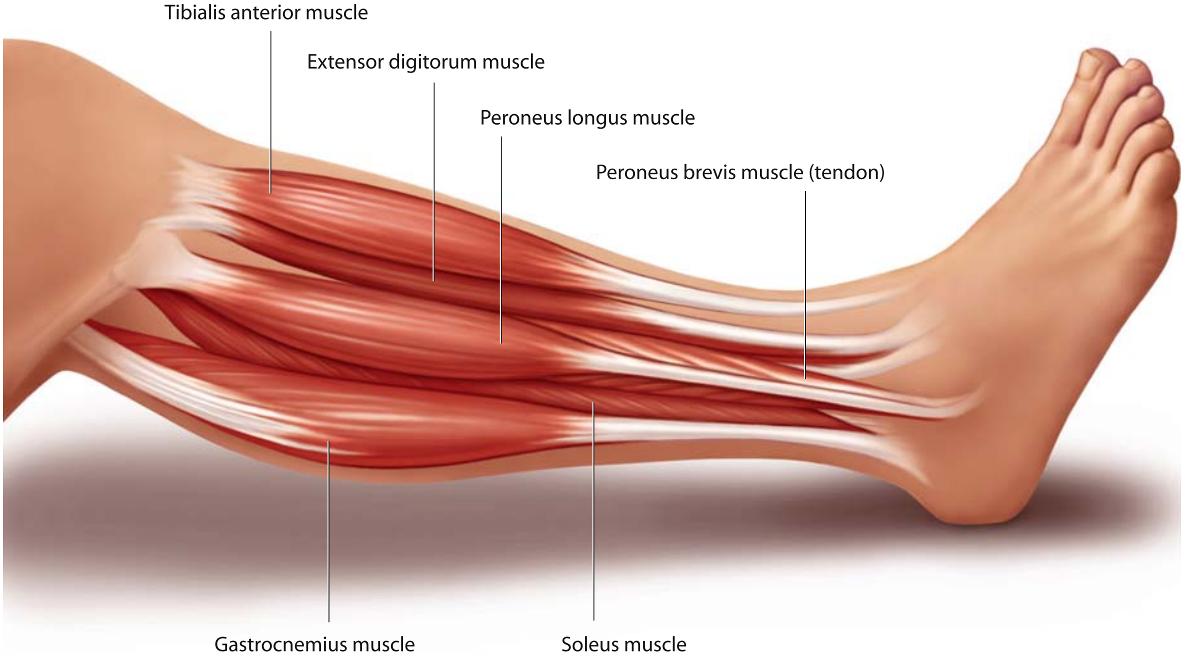
To obtain access to the flexor hallucis longus muscle from both sides, the skin paddle is now circumcised to the level of the crural fascia, which is included in the skin paddle to protect the perforating vessel. The fascia is circumcised using scissors, keeping a safe distance from the cutaneous vessel. Step 15

Bone, skin paddle, and the posterior intermuscular septum are elevated, and a cuff of soleus muscle is left attached to the septum around the perforator during separation of the skin paddle from the underlying muscles. Step 16

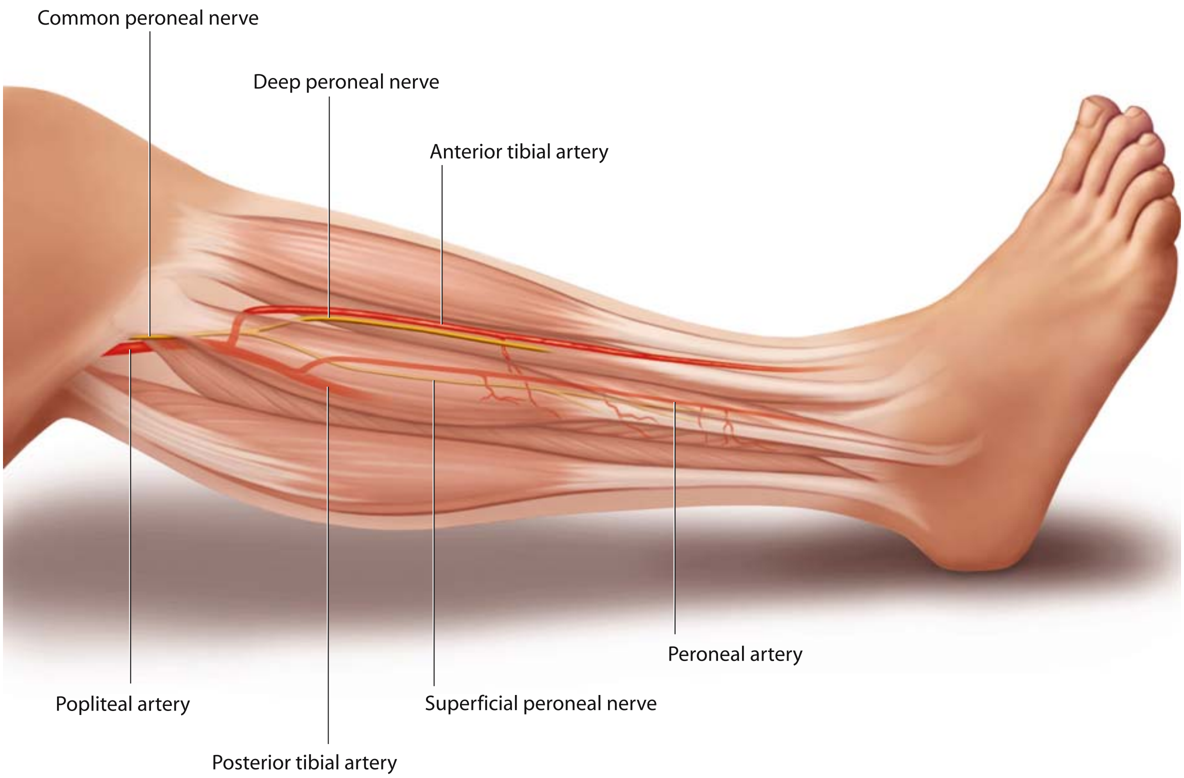
Keeping a distance of at least 2 cm from the bone, the flexor hallucis longus muscle and the posterior intermuscular septum are transected, and the flap can now be moved laterally. The peroneal vessels are completely covered by the muscle cuff built by the tibialis posterior and flexor muscles. The cutaneous perforator is seen in the middle of the posterior intermuscular septum. Step 17

At the proximal osteotomy, fibers of the flexor hallucis muscle are transected by carefully retracting the vascular pedicle. Step 18

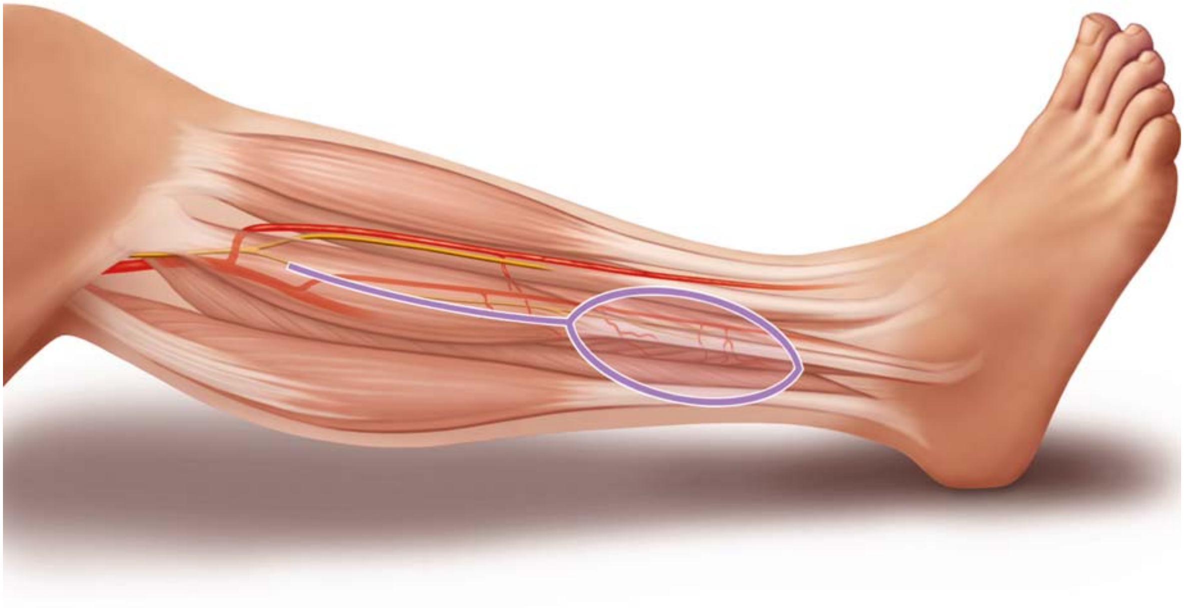
The flap is now ready for microvascular transfer. A longer pedicle can be obtained by further dissection of the peroneal vessels up to the level of the bifurcation with the tibial posterior vessels, but this is only necessary if a long bone segment is needed for reconstruction. Direct wound closure in the distal third of the lower leg is achieved if the width of the skin flap does not exceed 3 cm; in all other cases, a split-thickness skin graft is used to cover the donor-site defect. A deep drain is inserted, and the soleus and peroneus muscles are loosely attached to form a well-vascularized bed for the skin graft. The patient normally is immobilized for 3–4 days and then is allowed to walk with physiotherapeutic assistance. Foot pulses are controlled regularly during the first 24 h. Step 20

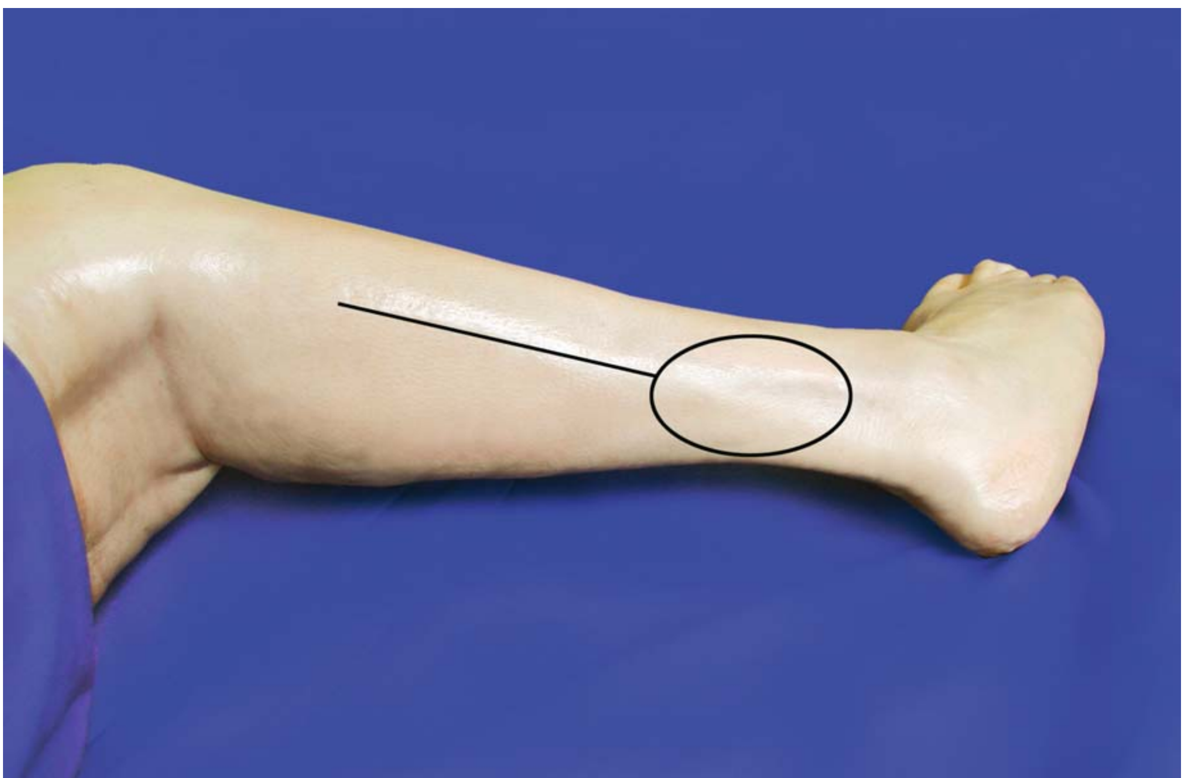


Muscles of the lateral lower leg

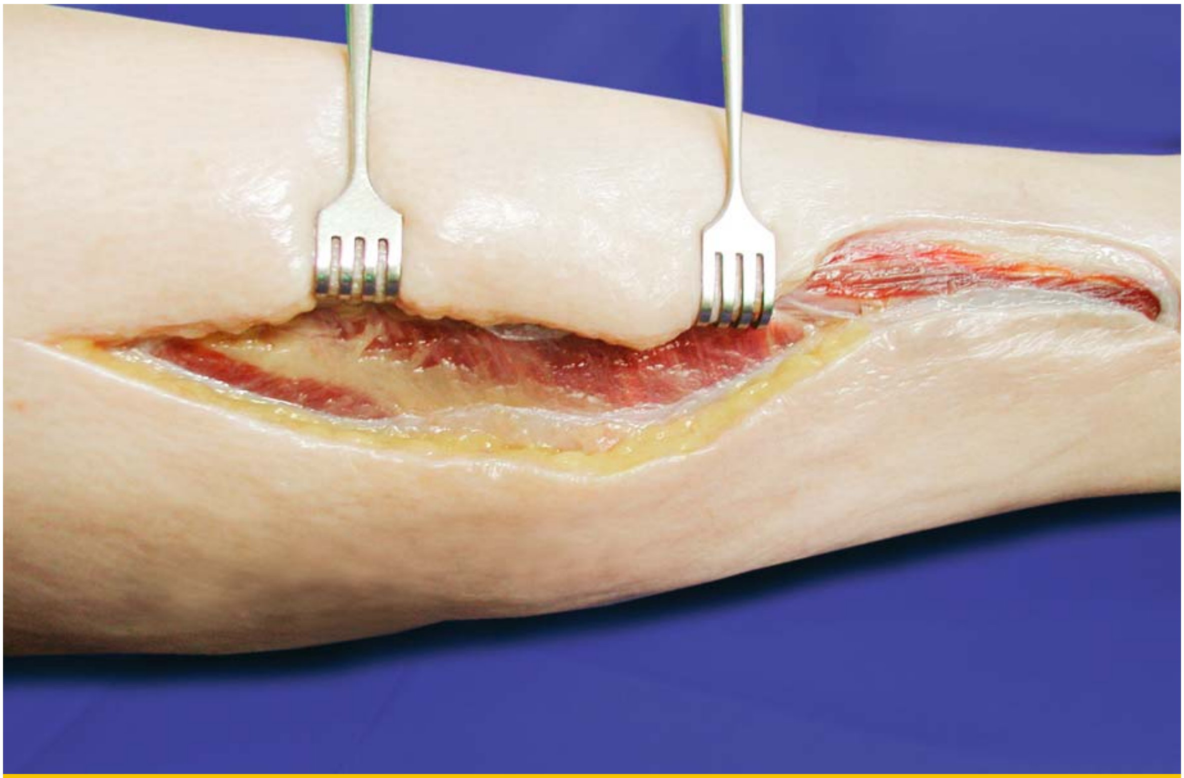


Arteries of the lower leg

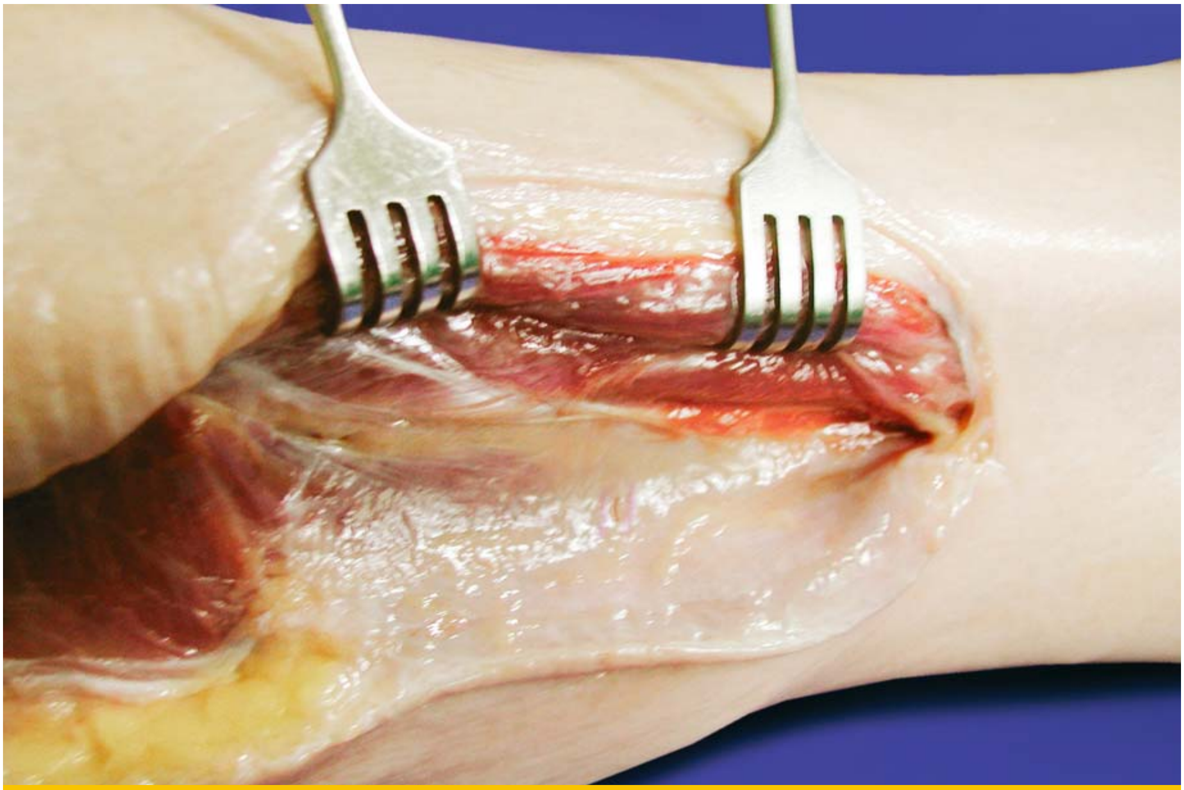




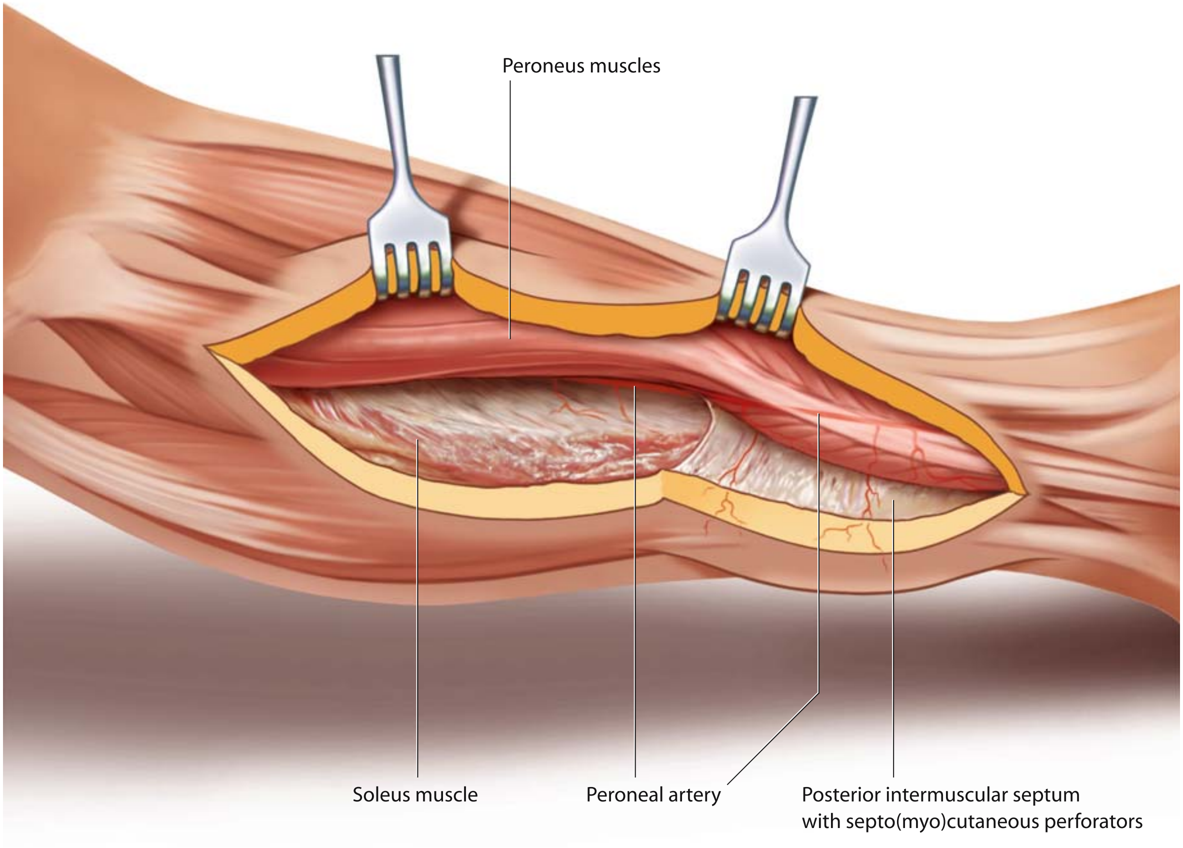
Patient positioning and flap design

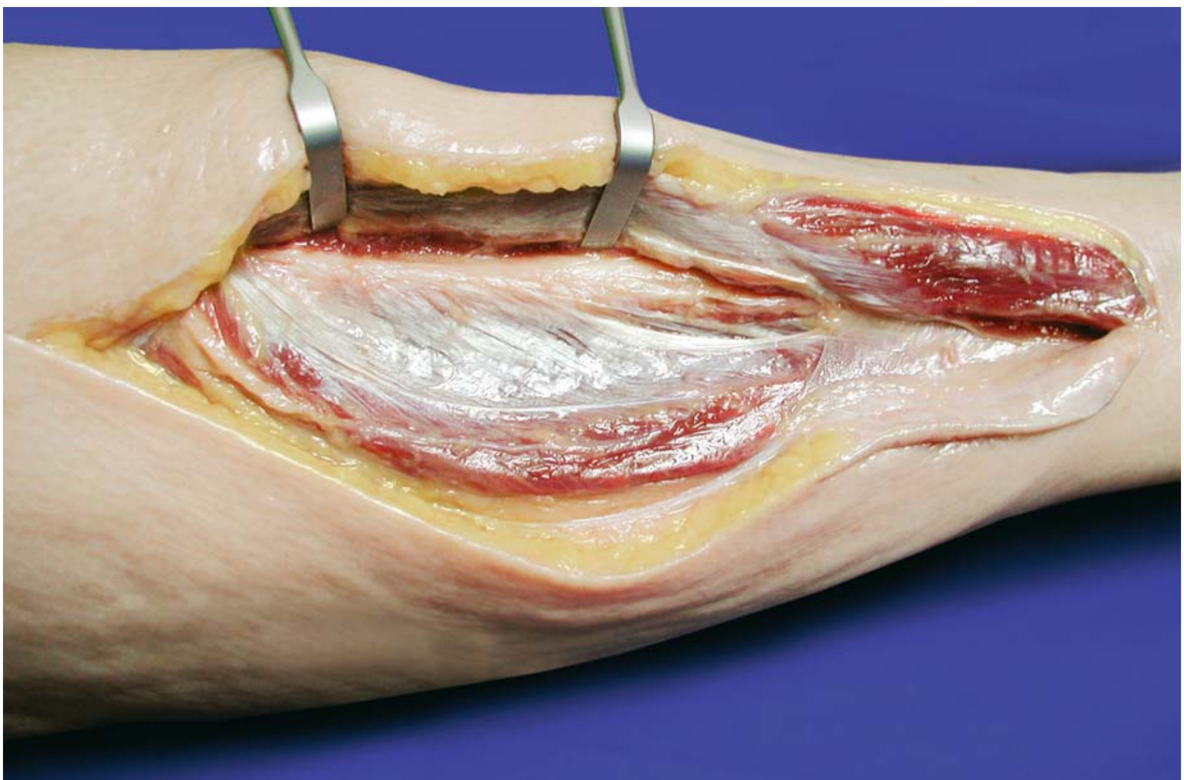


Step 1 • Incision of skin and fascia

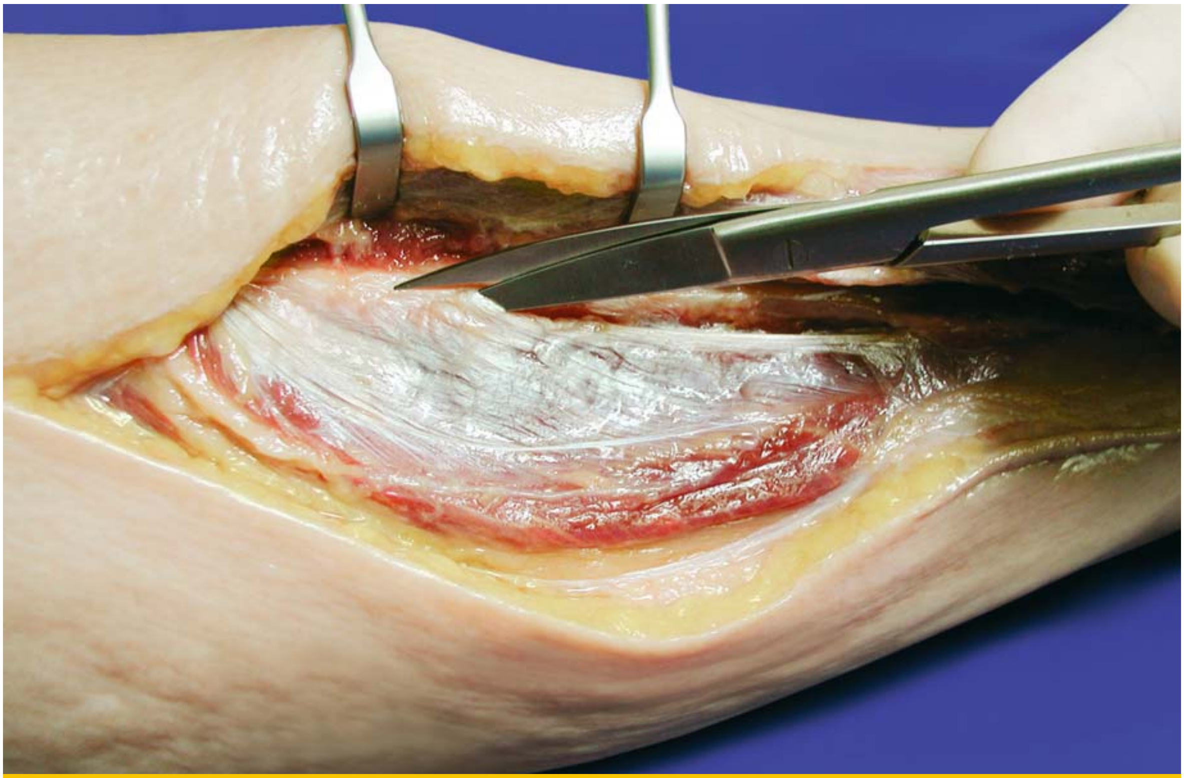


Step 2 • Identification of perforator

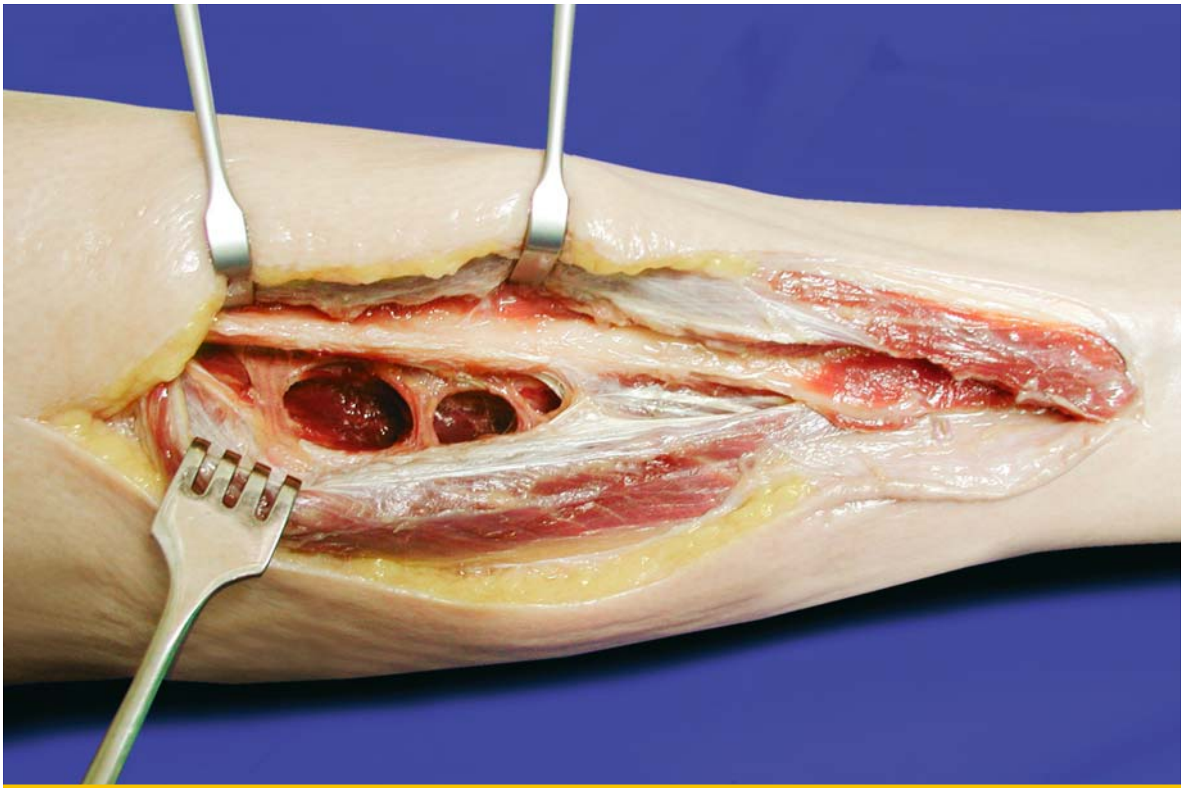




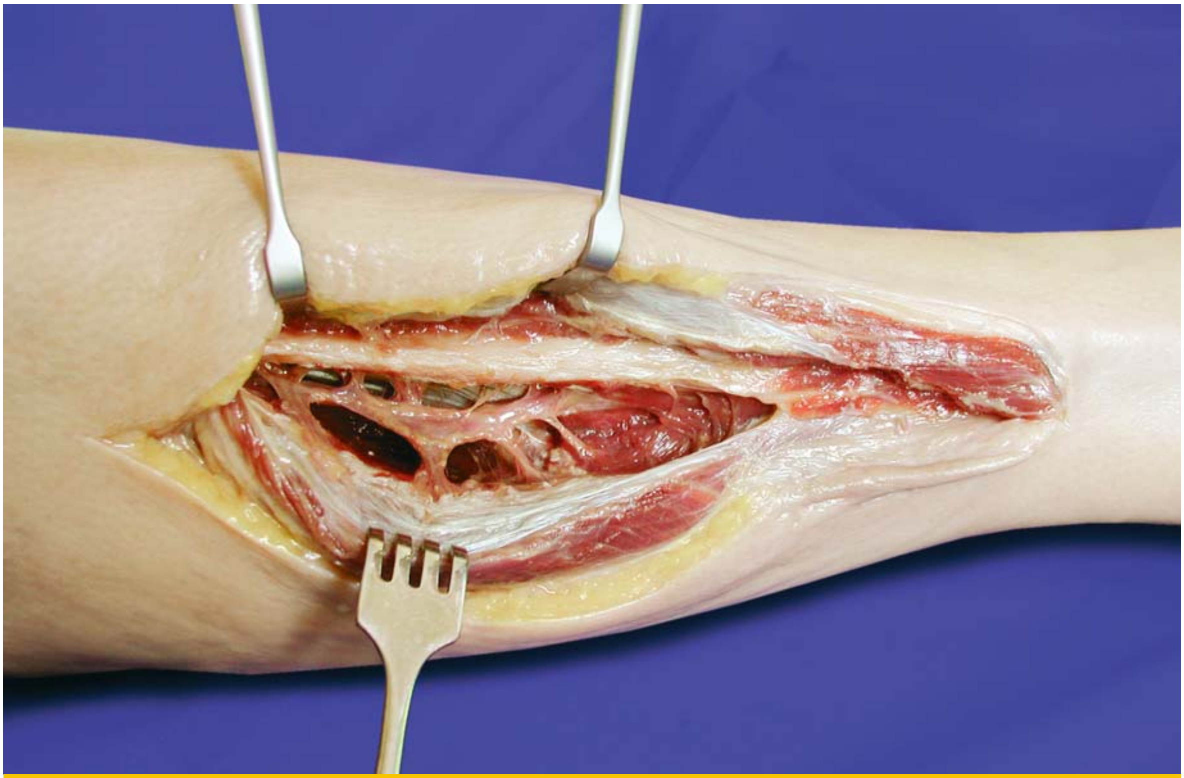
Step 3 • Exposure of lateral margin of fibula



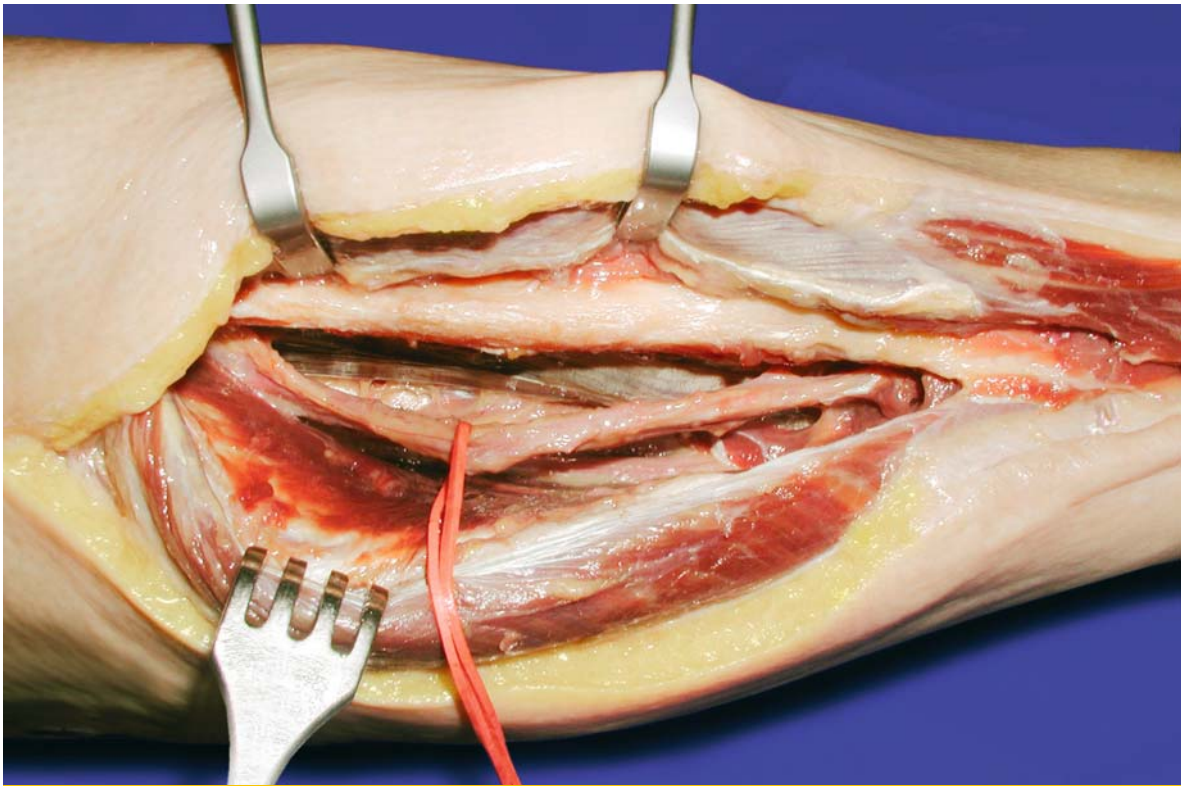
Step 4 • Detachment of soleus and flexor hallucis longus muscle



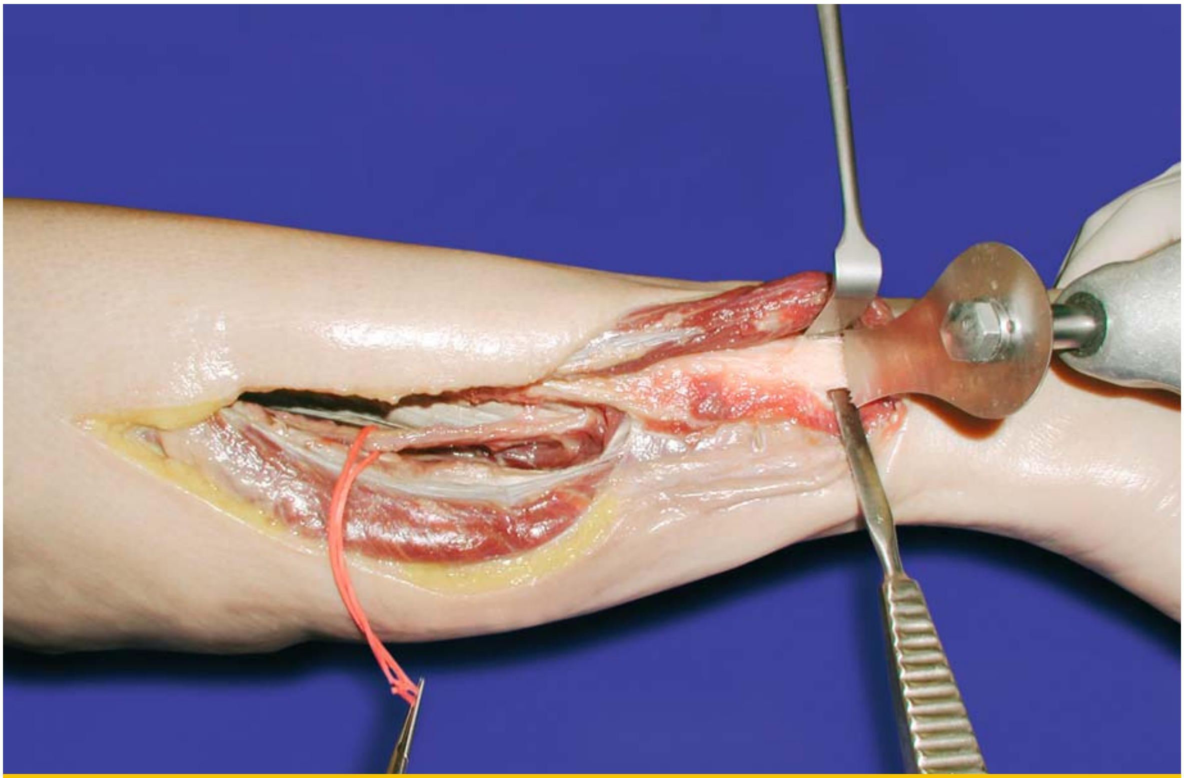
Step 5 • Opening of deep flexor space, identification of peroneal branches



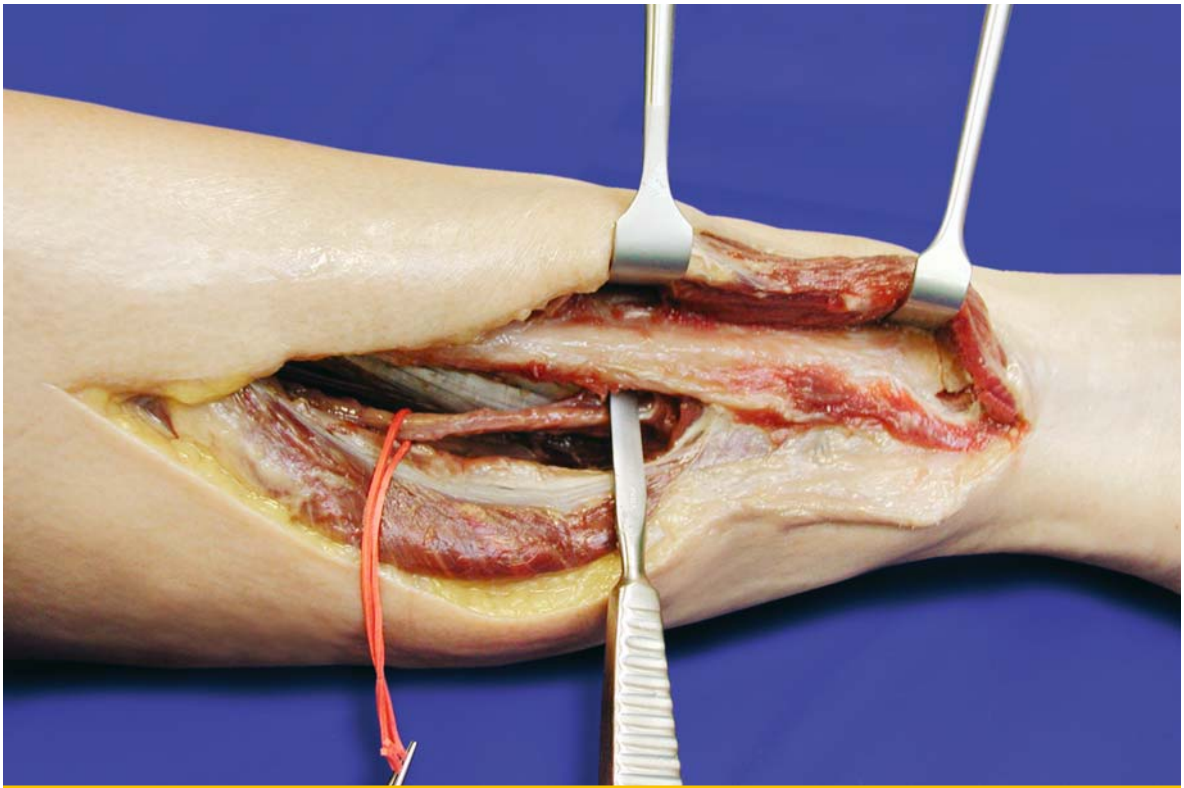
Step 6 • Exposure of peroneal vessels



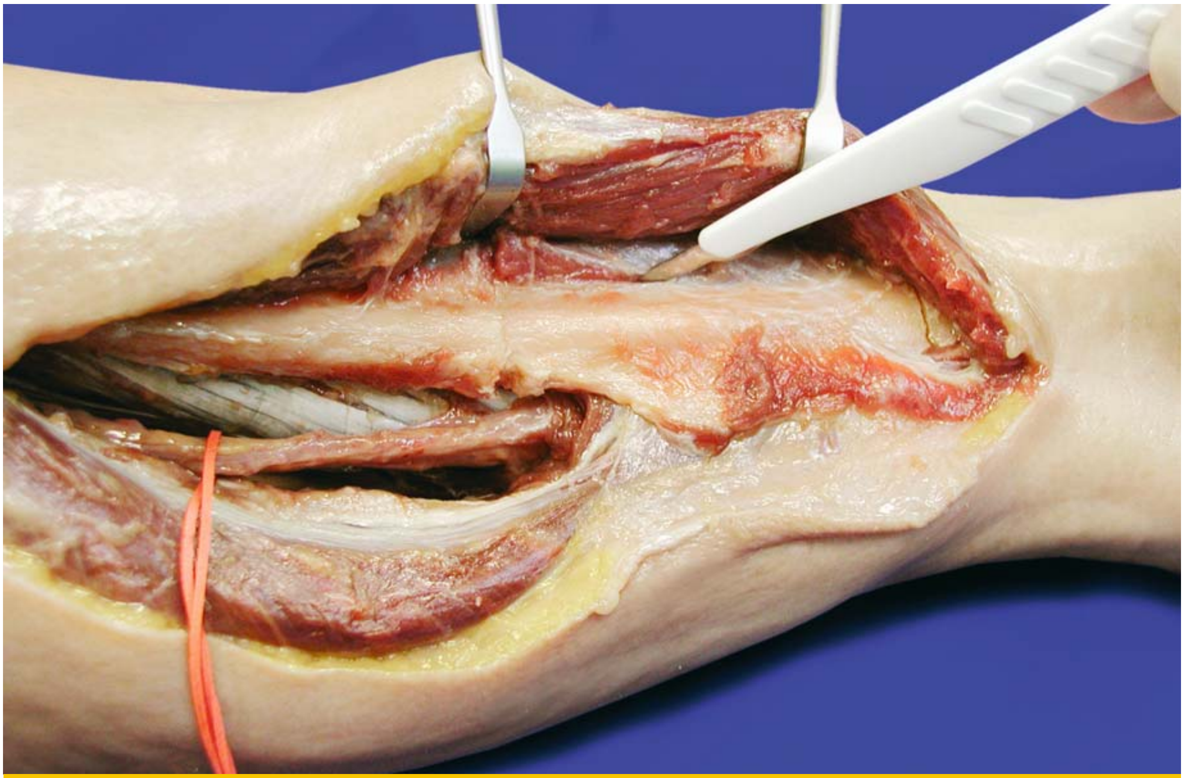
Step 7 • Dissection of vascular pedicle



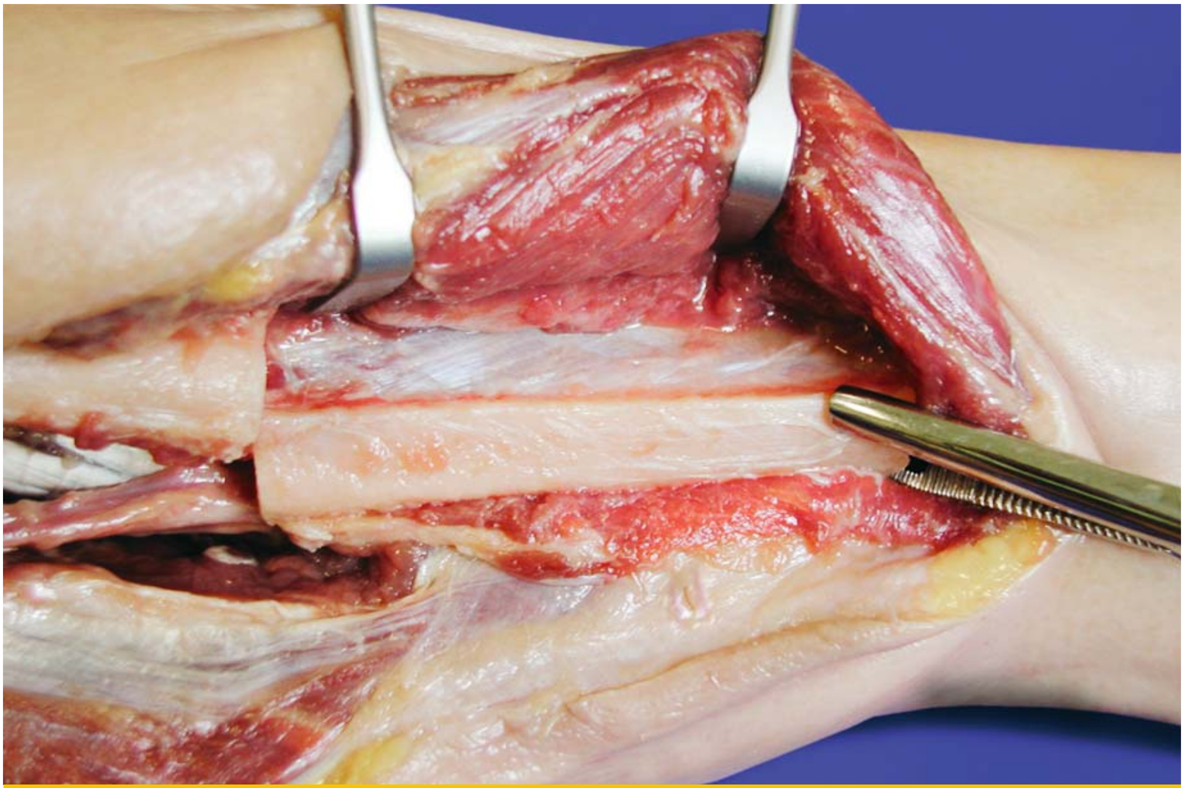
Step 8 • Distal osteotomy



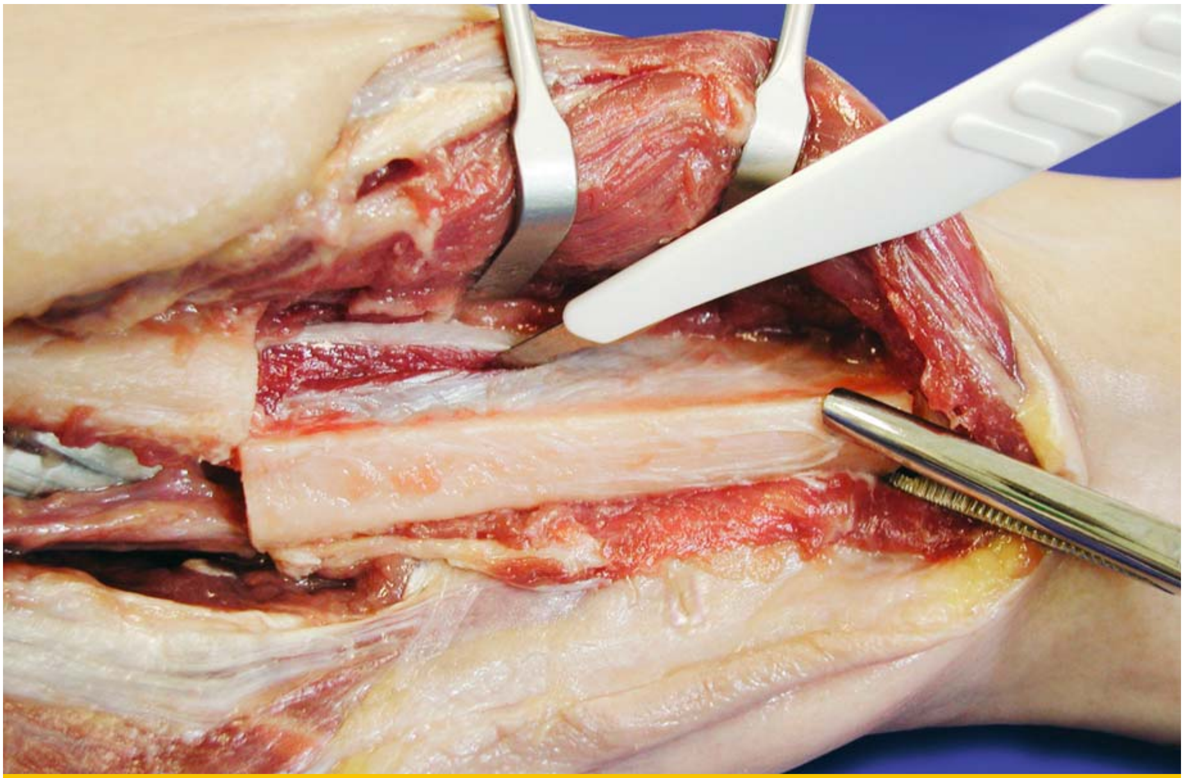
Step 9 • Proximal osteotomy, protection of pedicle



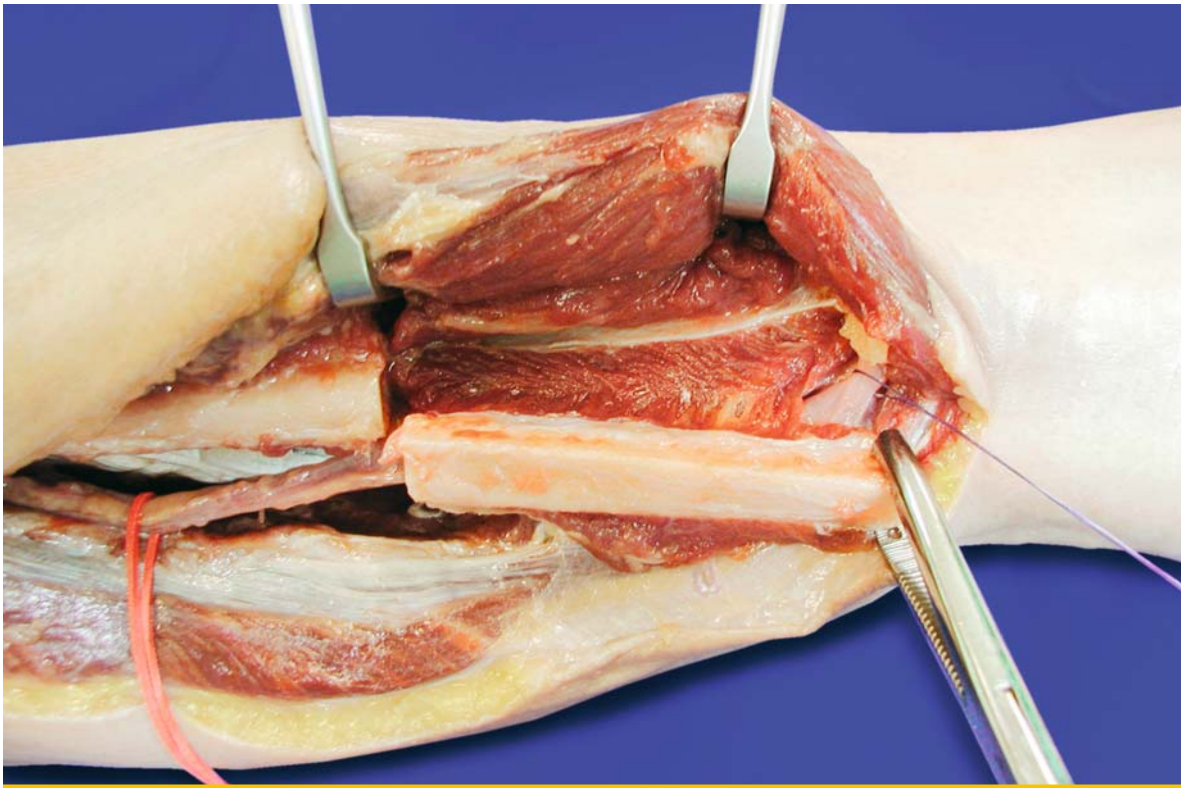
Step 10 • Incision of anterior intermuscular septum



Step 11 • Exposure of interosseous membrane

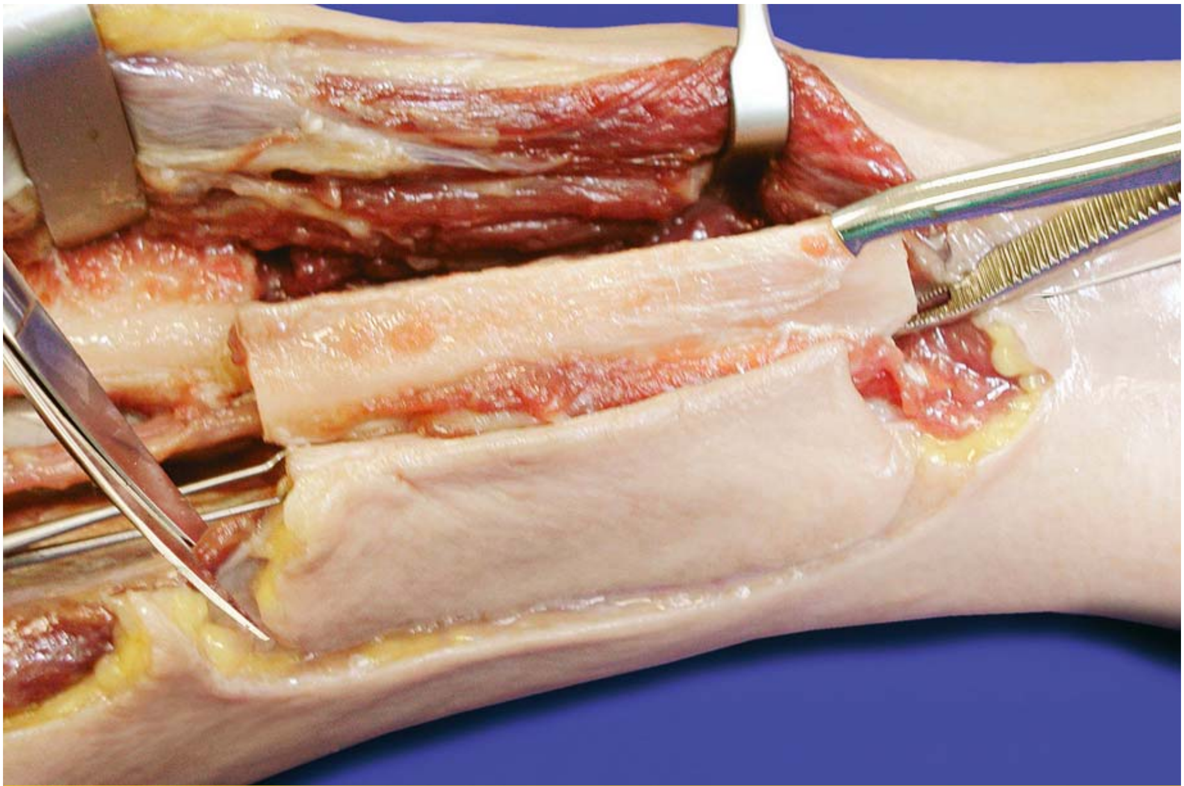


Step 12 • Transection of interosseous membrane

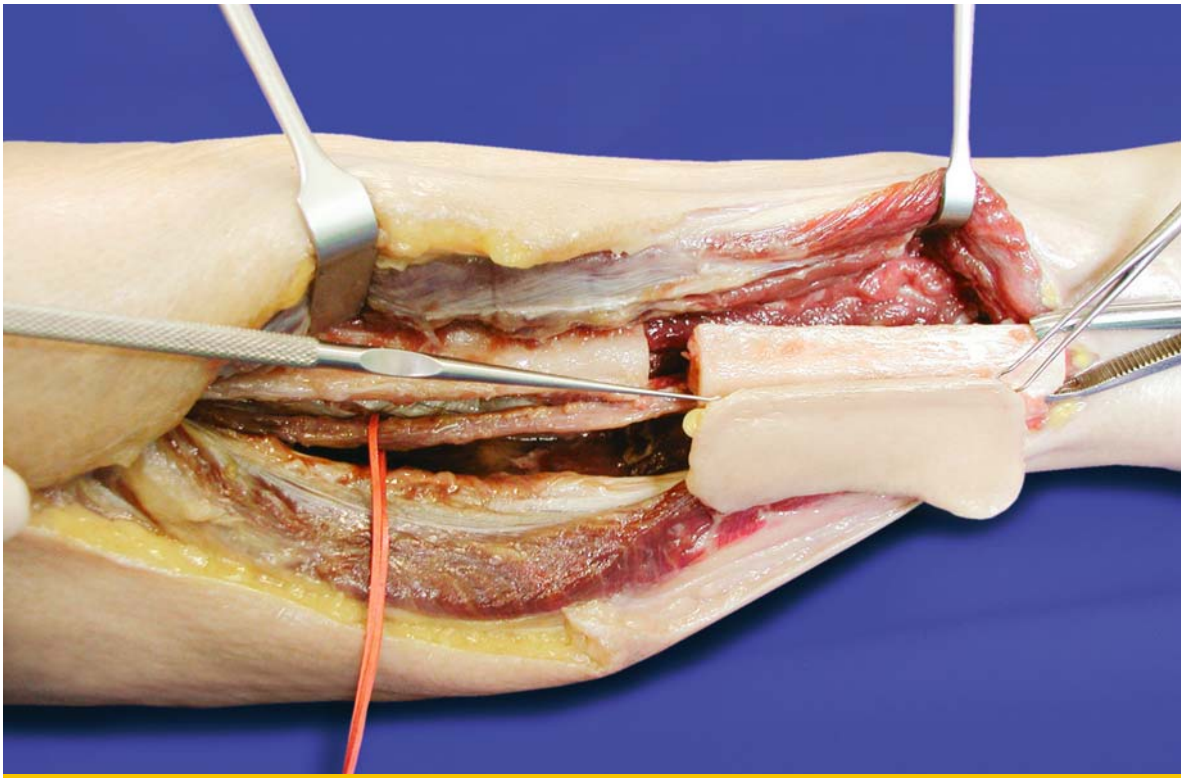


Step 13 • Distal ligation of peroneal vessels

Step 14 • Division of tibialis posterior muscle

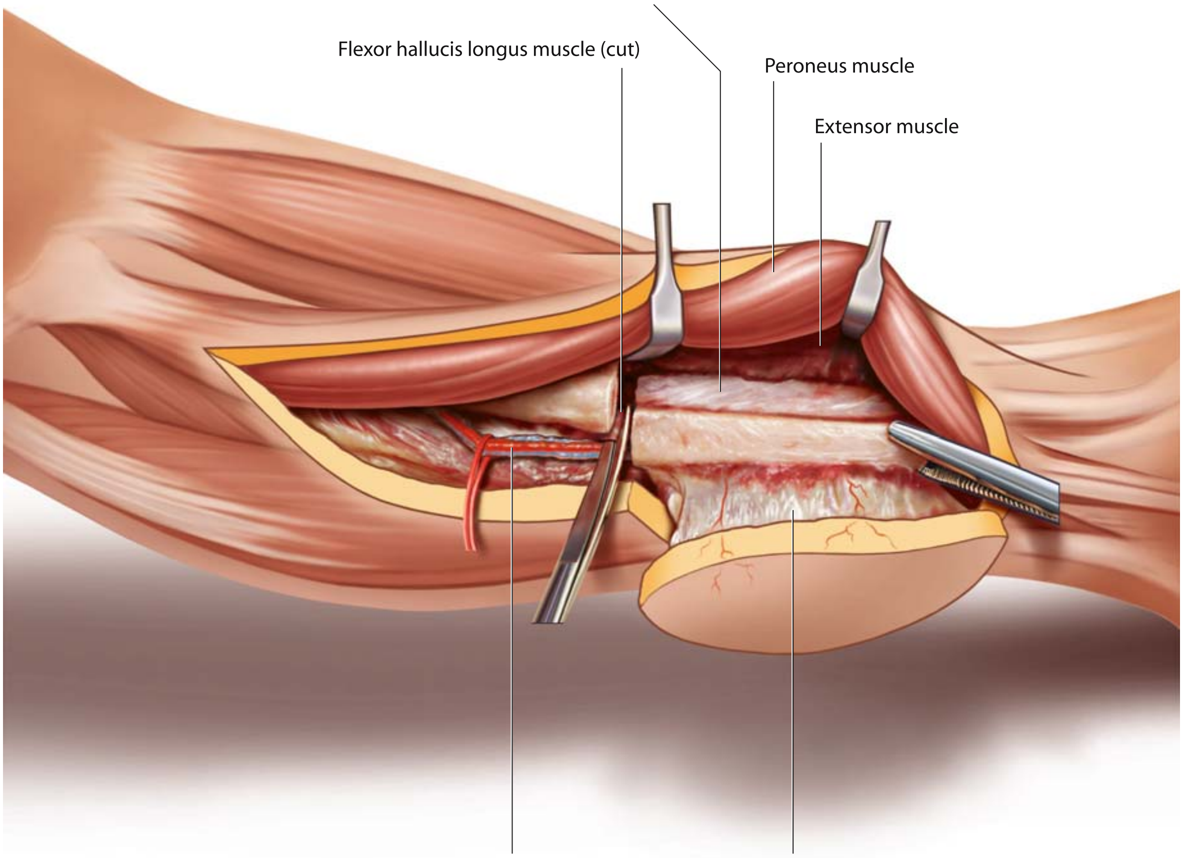


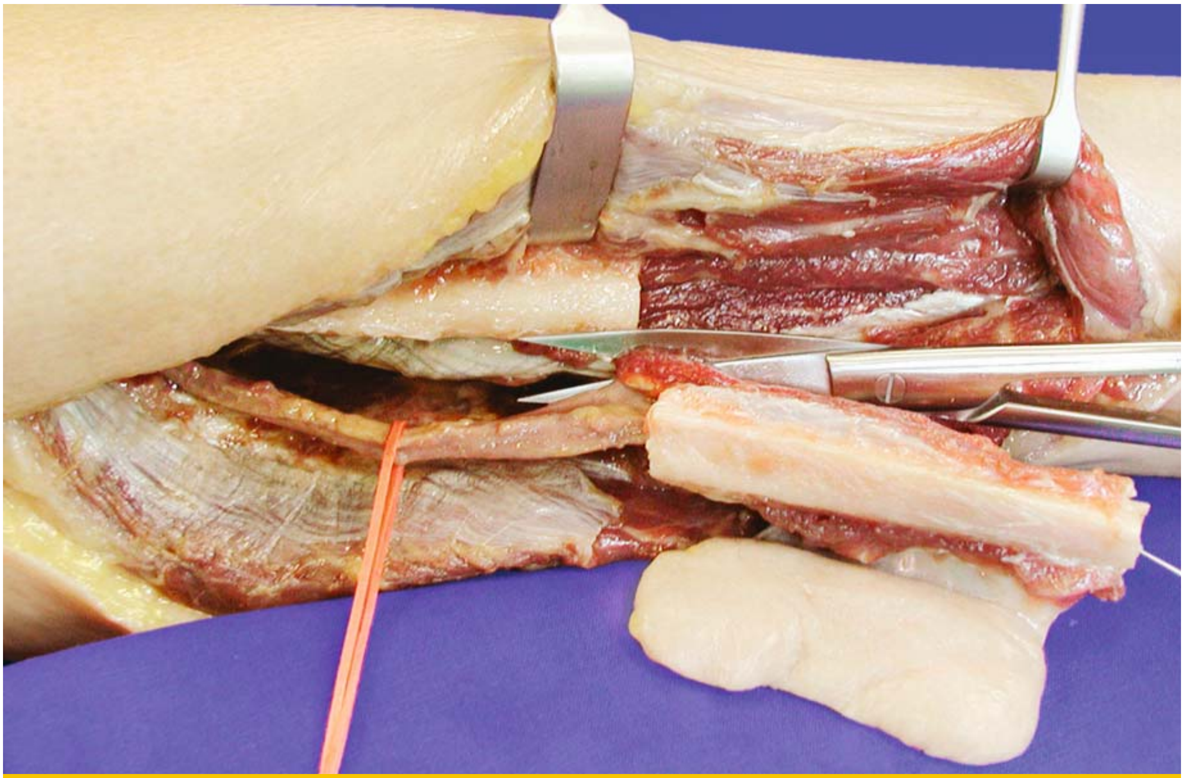
Step 15 • Incision of skin and fascia at dorsal periphery of skin paddle



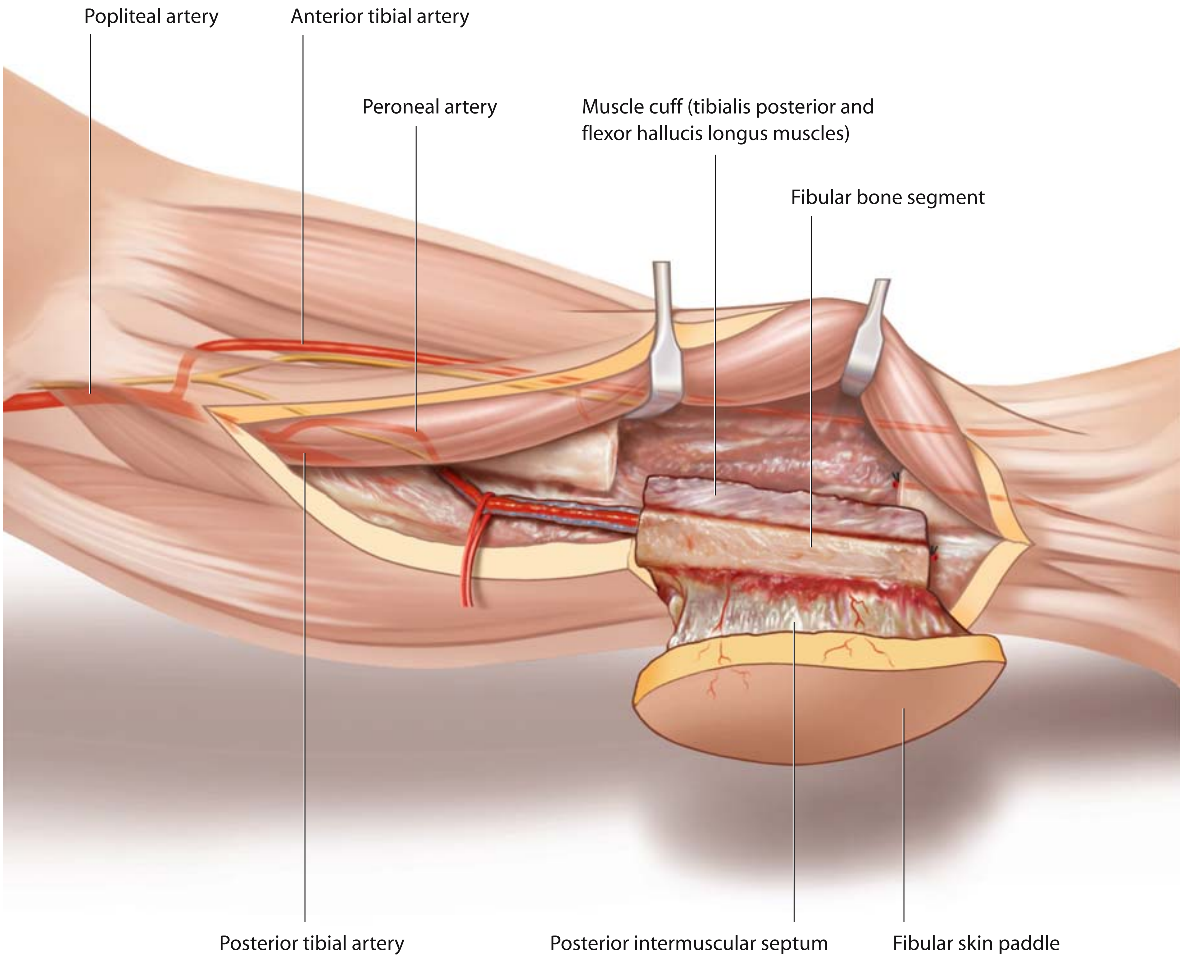
Step 16 • Complete elevation of skin paddle including muscle cuff around perforator

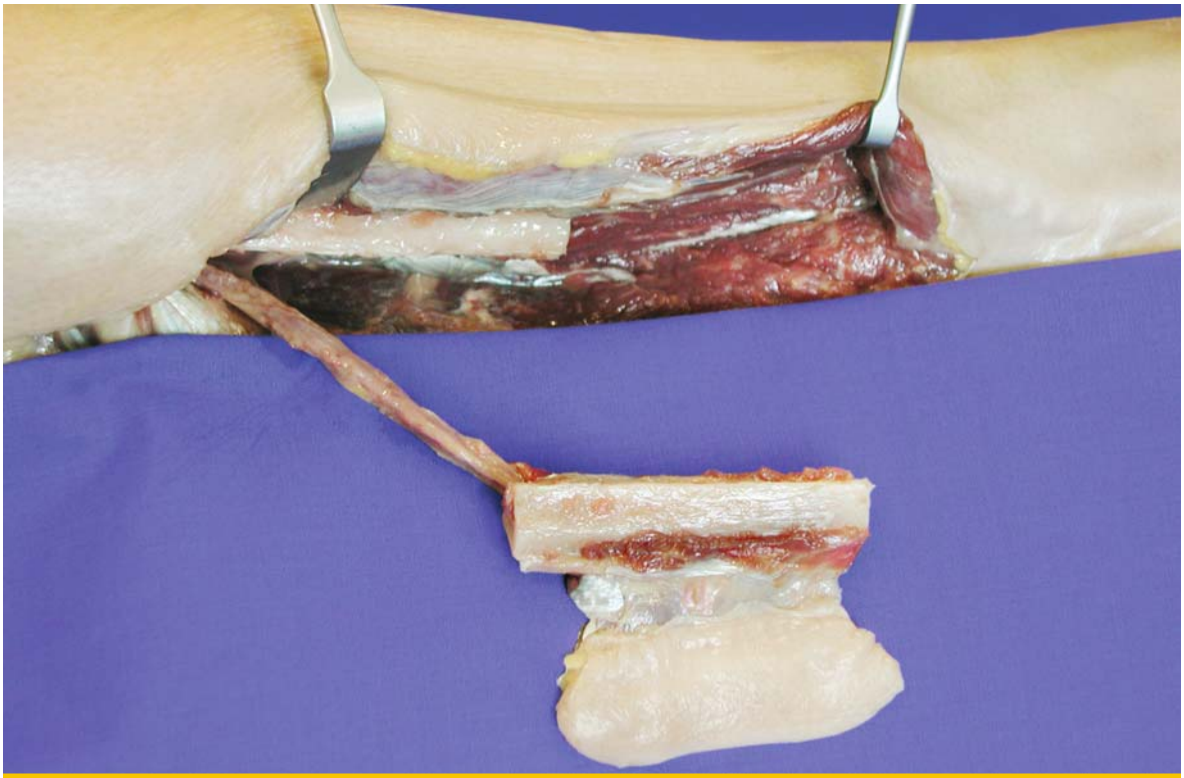
Step 17 • Distal transection of flexor hallucis longus muscle


Tibialis posterior muscle covered by interosseous membrane (cut)
Flexor hallucis longus muscle (cut)
Peroneus muscle
Extensor muscle
Peroneal artery and concomitant veins
Posterior intermuscular septum

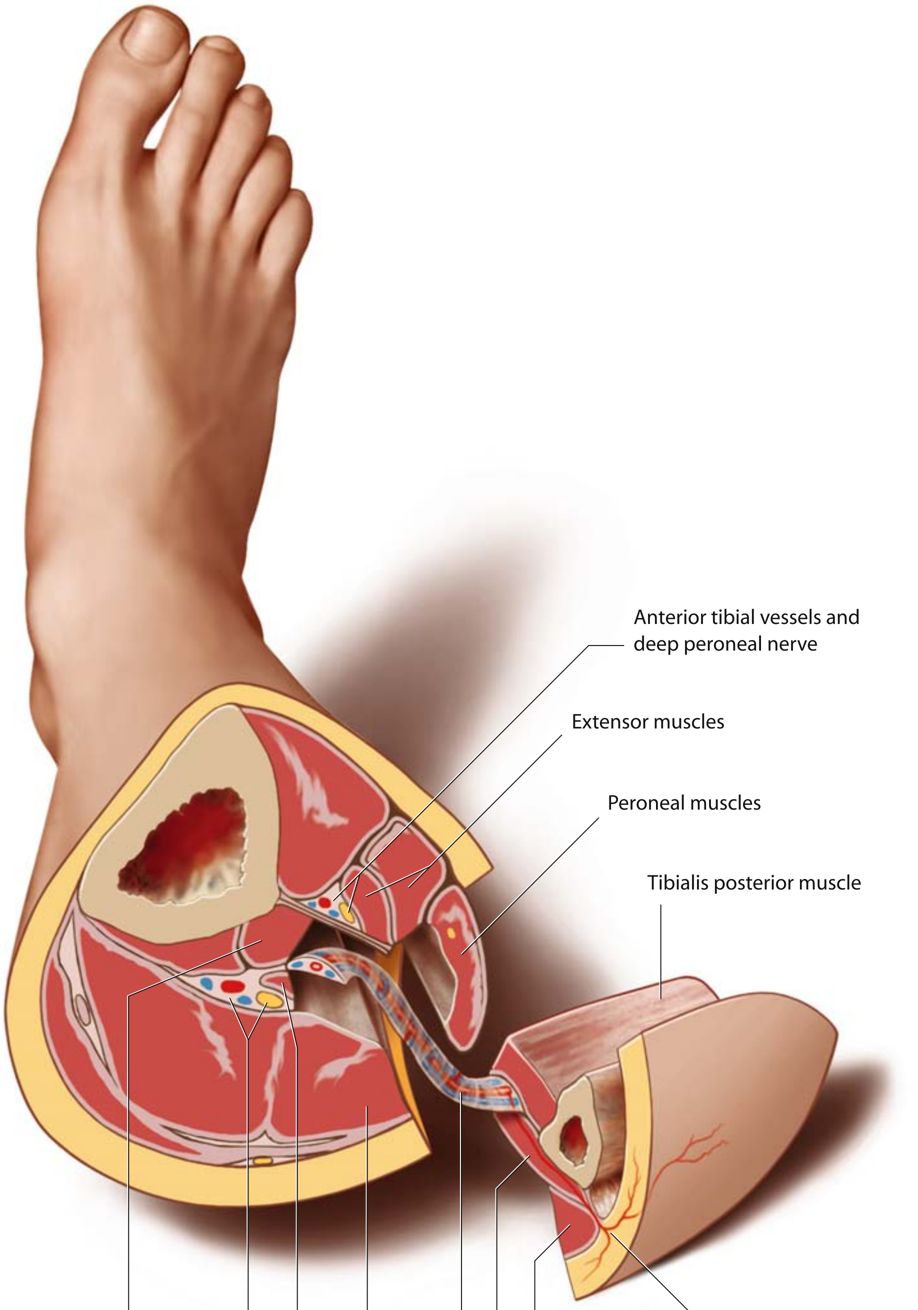


Step 18 • Proximal transection of remaining flexor hallucis muscle fibers


Popliteal artery
Anterior tibial artery
Peroneal artery
Muscle cuff (tibialis posterior and flexor hallucis longus muscles)
Fibular bone segment
Posterior tibial artery
Posterior intermuscular septum
Fibular skin paddle



Step 20 • Flap raising completed



Cross section anatomy of the osteocutaneous fibular flap and donor site

Comments

Flap Design

The posterior intermuscular septum is the key structure to design the skin paddle. Sometimes it is mistaken for the anterior intermuscular septum, which is located between the peroneus and the extensor muscles. The posterior intermuscular septum can easily be identified by palpating the groove between the Achilles tendon and peroneus muscles above the ankle, which then can be followed proximally.

Step 2: If no perforator is found at the transition of the middle and distal third of the lower leg, the whole septum has to be inspected, and another perforator is selected in the proximal calf. If no appropriate perforator can be identified along the whole septum, the contralateral leg should be considered for flap raising. This situation may occur in about 1% of all cases.

Step 3: The posterior intermuscular septum may only be opened proximal to the planned bone segment and must be left intact along the whole length of the fibular bone flap and skin paddle.

Step 4: Further septo(myo)cutaneous and muscular branches can be found while opening the posterior intermuscular septum and the deep flexor space. These vessels must be carefully ligated or clipped to prevent postoperative bleeding complications.

Steps 5, 6, 7: Exposure and dissection of the peroneal vessels may be difficult if the patient is not positioned properly. The knee must be bent and the hip elevated to obtain easy access to the dorsal aspect of the lower leg. During blunt separation of the muscle fibers, one of the concomitant veins becomes visible first. The location of the peroneal artery should always be checked by palpating the peroneus pulse dorsal to the fibula bone.

Step 8: The cutaneous perforator regularly sends a branch to the peroneal muscles, so bleeding will occur when forming the peroneus muscle cuff. A distance of about 1 cm should be maintained from the cutaneous branch in order to be able to cauterise the muscle bleeding without damaging the skin vessel.

Steps 8, 9: The posterior intermuscular septum must remain intact along the whole length of the osteotomized fibular segment, as this will guarantee the protection of the septocutaneous vessel and the attachment of the skin paddle to the bone.

Steps 10, 12: For incision of the anterior intermuscular septum and the interosseous membrane a sharp scalpel should be used and the underlying muscles should not be violated.

Step 13: The distal peroneal vessels should be exposed carefully to prevent bleeding from the veins and so that safe ligation is possible.

Step 14: During transection of the tibialis posterior muscle bleeding will occur from branches connecting to the tibial posterior artery and branches to the surrounding muscles. These vessels should be carefully clipped or cauterized.

Step 15: The sural nerve and small saphenous vein may become exposed at the dorsal periphery of the skin flap and might need ligation.

Step 16: To facilitate elevation of the flap, the skin paddle should be held between two fingers to protect the septum and the cutaneous vessel from both sides. A cuff of soleus muscle should be left along the whole length of the septum, with the greatest thickness about 1 cm around the perforator.

Step 17: When the posterior intermuscular septum is transected dorsal to the tibialis posterior muscle, great mobility is achieved, and the flap can now easily be moved laterally. Further medially, the tibial nerve and the tibial posterior vessels will become visible. Great care must be taken not to injure these structures.

Chapter 7

Iliac Crest Bone Flap

Development and Indications

The possibility of transferring bone blocks of the ileum as parts of composite flaps from the groin donor site was described in anatomical studies by Taylor et al. in 1979 [257]. Whereas the blood supply of the SCIA was excellent to the skin, the bone blocks of the iliac crest were only perfused marginally by these vessels. Other vascular pedicles around the hip, such as the ascending branch of the circumflex femoral artery or the superior gluteal artery, were also used for microvascular transfer of composite flaps containing bone from the iliac crest [11, 85]. Although the vascular anatomy of the groin region, which was the first donor site for free flaps [6], had already been investigated by Taylor and Daniel in 1973 [254], it was 1978 before Taylor and Watson [256] and Sanders and Mayou [216] described the first transfer of the iliac crest bone, using the deep circumflex iliac artery (DCIA) as the vascular pedicle. Both groups independently identified the DCIA to be the main nutrient vessel of the whole iliac crest. Since these first reports, the iliac crest has proved to be a useful and reliable donor site, and because of its anatomical shape it is ideally suited for the harvest of bone flaps to reconstruct defects of up to half a mandible [1, 20, 21, 58, 66, 71, 124, 125, 201, 258, 259, 269, 270]. As a result of the high amount of bone available, enosseous dental implants can be inserted without problems, making the iliac crest the donor site of first choice for functional masticatory reconstruction of the mandible and maxilla [201]. Sanders and Mayou have also shown that the DCIA provides blood to the overlying skin of the iliac crest by myocutaneous vessels [216]; thus, a skin paddle from the groin region can additionally be included and used for extra- or intraoral reconstruction [124, 201, 269, 270]. Other flaps, such as the anterolateral thigh flap, have been additionally transferred together with the iliac crest [136] to extend the skin territory for soft-tissue reconstruction, performing additional anastomoses at the descending branch of the circumflex femoral artery. Because of the bulk and limited flexibility of the iliac crest skin paddle, Urken and coworkers introduced inclusion of the internal oblique muscle into the flap [269, 270, 273]. He proposed using this flat, flexible muscle for intraoral lining instead of the voluminous skin paddle. Although it had already been shown by Ramasastry et al. in 1984 [196] that the internal oblique muscle is safely perfused by the ascending branch of the DCIA, thus offering the possibility of building a vascularized myo-osseous iliac flap pedicled on the DCIA, the internal oblique muscle was only used as a isolated muscle flap until Urken's description. In addition to the decreased bulk, covering the iliac crest with the internal oblique muscle is advantageous for prosthetic rehabilitation following the insertion of enosseous dental implants. Owing to secondary atrophy of the muscle, a tight, flat residual tissue will develop that is similar to that of the attached gingiva, allowing for good hygiene and loadability around the implants. The iliac crest internal oblique flap has also proven to be useful in covering skull-base defects and in reconstructing the hard palate.

Anatomy

The anatomy of the DCIA was first described by Taylor et al. in detail [257]. The artery arises directly cranial (58 %) to the inguinal ligament from the external iliac artery or directly caudal to it from the femoral artery (42 %), mostly opposite the inferior epigastric artery [111]. The diameter of the artery varies between 1.5 and 3 mm [19, 189, 257]. Two concomitant veins are usually found, which merge 1–2 cm before entering the external iliac vein; here, the vein has a caliber of 3–5 mm. Between the transversalis and iliacus fascia, the vascular pedicle courses towards the anterior superior iliac spine (ASIS), about 2 cm cranial to the connecting line between the tuberculum pubicum and the ASIS, representing the inguinal ligament. After reaching the anterior margin of the iliac crest approximately 2 cm inferior to the ASIS, the DCIA courses along the inner aspect of the ileum dorsally, being located in the groove formed by the iliacus and transversus muscles. In the region of the iliosacral joint, the DCIA anastomoses with the ileolumbar artery, which has an outer diameter of 2 mm and can also serve as the vascular pedicle if the DCIA has been transected following previous surgery [40]. During its course the DCIA gives off several branches to the iliacus muscle, as well as periosteal and medullary perforators to the iliac crest. Moreover, the DCIA gives off the ascending branch, which runs at the undersurface of the internal oblique muscle. During its course along the inner aspect of the ileum, a number of myocutaneous perforators arise from the DCIA, piercing all three muscle layers of the abdominal wall. These three to nine fine perforators enter the skin within an approximately 2.5-cm broad cuff of oblique muscles, beginning at the ASIS and reaching about 10 cm distally. This muscle cuff always has to be incorporated when elevating a skin paddle. If the bulk of the muscle cuff should be reduced, a perforator-based skin paddle can be harvested if the exact location of the perforating vessel to the skin has been confirmed by ultrasound preoperatively [130]. In addition to the above-mentioned periosteal and medullary branches, the bone is additionally supplied by the well-perfused cuff of the iliacus and oblique muscles, which must be left attached to the bone during flap harvesting. Based on the results of anatomical studies and clinical experience, bone flaps can include the whole iliac crest, extending from the SIAS up to the iliosacral joint [19, 20, 21, 189, 201, 216, 257, 273]. Angiographically, Taylor was able to identify a number of foramina at the iliac crest, allowing the DCIA to anastomose with branches from the inferior gluteal artery, providing the anatomical basis to include parts of the gluteus muscle in the flap [257]. These findings were confirmed using dye injections, which have also shown that the skin paddle supplied by the DCIA can be extended along the whole ileum, reaching close to the inferior rib arch. The most important side branch of the DCIA is the ascending branch, which mostly (80 %) arises from the vascular pedicle before it reaches the ASIS [273]. In the remaining cases, multiple smaller branches can be found that reach the undersurface of the internal oblique distolaterally to the ASIS. Another branching pattern was described by Taylor, who found the ascending branch to spring off in one-third of the cases from the proximal, intermediate, and distal segment of the vascular pedicle between the iliac artery and the ASIS [257]. This branch, measuring 1–2 mm in diameter, provides the dominant blood supply to the internal oblique muscle, but it does not contribute to skin perfusion. This branch allows for integration of nearly the whole internal oblique muscle, which can be used for intraoral lining [66, 269, 270, 273]. Another side branch can regularly be found just proximal to the ASIS to reach the iliacus muscle. The lateral femoral cutaneous nerve, which mostly crosses the DCIA superficially, provides sensation to the lateral and proximal aspect of the thigh. Although this cutaneous nerve can be identified medial to the ASIS and preserved by meticulous dissection, it often is sacrificed during dissection. Numbness in the thigh does not seem to bother the patients. The vascular pedicle has never been found to be absent [273], and besides the above-mentioned variations concerning the ascending branch, only the veins join in a variable distance from the external iliac vein, exeptionally making two separate anastomoses necessary. Moreover, in rare cases the DCIA can be duplicated [222, 273], so the decision as to which of the two arteries provides the most reliable blood supply to the flap must be made by temporary clamping. Because of its variable exit and strong caliber, the ascending branch can be mistaken for the DCIA, especially in those rare cases when the DCIA passes through the transversus muscle medially to the ASIS, so that it travels more superficially along the iliac crest [257].

Advantages and Disadvantages

Because of the extensive amount of bone and the various possibilities for designing the bone flap, the iliac crest is supposed to be the ideal donor site for mandible reconstruction; moreover, the flap has the potential to be used for other osseous defects at the maxilla, skull base, tibia, metacarpus, and many other parts of the skeleton [66, 187, 201, 222, 258, 259, 273]. To restore masticatory function, augmentations to the severely atrophied mandible have been performed using this flap, which allows for insertion of dental implants without difficulty [201]. The anatomy of the vascular pedicle does not have significant variations, and the donor-site morbidity normally is low, even if extensive bone flaps have been removed, including the ASIS. To prevent complications at the donor site, wound closure must be performed by an experienced surgeon. After accurate hemostasis, the iliacus muscle is attached to the transversus muscle, using multiple, deep sutures, which additionally can be placed through drill holes along the cut margin of the pelvic bone. Next, the internus and externus oblique muscles are approximated to the tensor and gluteus muscles. Finally, the subcutaneous fatty tissue and the skin are closed in layers. The patient is immobilized for 3–4 days, and ambulation is begun under physiotherapeutic assistance. Nevertheless, a number of complications at the donor site have been described, such as herniation (9.7%), long-lasting pain

(8.4%), neuropathy (4.8%), and impotence (1.2%) [75]. Moreover, injury to the iliohypogastric and ilioinguinal nerves is possible, as these nerves penetrate the muscles of the abdominal wall [153].

The length of the vascular pedicle is limited to about 7 cm, sometimes making anastomosis difficult, especially after radical neck dissection. In these cases, interpositional vein grafts have to be used to lengthen the pedicle [125, 187]. Owing to the voluminous skin paddle, osteomyocutaneous iliac crest flaps are often too bulky for intraoral reconstruction [187, 273]. Moreover, the reliability of the skin paddle can easily be reduced by kinking, stretching, or compression of the fine myocutaneous perforators. Thus, the skin island has to be handled without any tensile or compression forces, and it must always be designed large enough to capture a high number of myocutaneous vessels, making skin perfusion reliable. Despite this, venous drainage of the skin can be insufficient in up to 20% if only the deep vascular system is used [124, 125, 187]. Because of this, these authors and others as well emphasize that a second venous anastomosis to the superficial venous system must be performed [124, 187, 216].

Flap Raising

Patient Positioning

The patient is placed in a supine position with the buttocks on the donor site elevated by a beanbag. The operating field is prepped between the midline, posterior axillary line, lower rib arch, and upper thigh. For mandible reconstruction, the ipsilateral hip is selected if the defect involves the ramus and angle and extends to the anterior arch and if the recipient vessels arise in the region of the angle. If a skin paddle is needed for intraoral lining, the opposite hip is selected; if the skin paddle is to be placed extraorally, the flap is raised from the ipsilateral side. Because of the constant anatomy, no preoperative measures are necessary to reveal the course of the flap vessels.

Flap Design

Bone segments of up to 8 × 18 cm can be harvested from the whole iliac crest, keeping a safe distance from the acetabulum and iliosacral joint. For mandibular reconstruction, the ASIS is used to build the angle, extending the bone flap along the iliac crest to form the body and anterior arch. The anterior border of the pelvis between the ASIS and the inferior spine is used to form the ramus of the new hemimandible. Even if the angle is not involved, inclusion of the ASIS will facilitate flap raising and does not negatively affect the appearance or morbidity of the donor site. Elliptic skin islands are outlined along the curvature of the iliac crest, with the axis running at a distance of 2.5 cm parallel and medial to the iliac crest. Skin islands must always be large enough to include perforators in a zone between the ASIS and approximately 10 cm posterior to the ASIS.

Flap Raising

Step 1

To raise a myo-osseous flap without a skin paddle, the incision is outlined 2 cm superior to the connection of the pubic tubercule and the ASIS, starting just lateral to the pulse of the femoral artery. For further exposure of the pelvic bone, the incision is drawn directly above the curvature of the iliac crest far enough distally to allow for easy detachment of the gluteus muscles.

Step 2

Skin and subcutaneous fatty tissue are incised between the femoral artery and the ASIS, and the inguinal ligament is identified. The superficial epigastric vessels may run across the incision line and are ligated and divided.

Step 3

The inguinal ligament that forms the aponeurosis of the external oblique muscle is incised parallel to the orientation of the ligament fibers, and the internal oblique muscle readily becomes visible. The orientation of this muscle is perpendicular to the fibers of the inguinal ligament. Skin and ligament are retracted in a cranial direction.

Step 4

The internal oblique muscle is transected with scissors 2 cm superior to the connection of the ASIS and the pubic tubercule, and loose fatty tissue becomes visible, covering the thin transversalis fascia. The pulse of the DCIA is easily palpated in the groove formed by the transversus and iliacus muscle, and the vascular pedicle is exposed by careful and mostly blunt separation of the fatty tissue. It is not necessary to expose the external iliac artery for identification of the DCIA.

Step 5

A vessel loop is placed around the artery, which is accompanied by two veins, and the pedicle is dissected along its course to the ASIS. Few branches to the surrounding muscles must be clipped or ligated. The ascending branch that courses along the undersurface of the internal oblique muscle is identified. If the lateral femoral cutaneous nerve crosses above the vascular pedicle, it is also transected.

Step 6

Once the vascular pedicle has been isolated just medial to the ASIS, the skin incision is continued along the iliac crest to the level of the external oblique muscle.

Step 7

The lateral rim of the iliac crest is palpated, and the muscles are now transected at the gluteal aspect of the pelvis. Consistent hemostasis has to be performed to prevent diffuse bleeding from the well-perfused muscles.

Step 8

Beginning anteriorly, the tensor fasciae latae and gluteus medius muscles are detached epiperiosteally from the external surface of the hip, while the sartorius muscle is still left intact. Again, careful hemostasis is necessary. The muscles of the abdominal wall are retracted in a cranial direction and bluntly undermined medial to the iliac crest, maintaining a dissection plane superficial to the vascular pedicle.

Step 9

Keeping a distance of 2 cm to the inner rim of the iliac crest, the abdominal muscles are transected with scissors from a caudal to a cranial direction, and further muscular branches to the internal oblique muscle are cauterized or ligated. The pulse of the DCIA is palpated at the inner surface of the pelvic curvature 1–3 cm inferior to the inner rim and therefore can easily be preserved during transection of the muscles. A broad abdominal hook is inserted to protect and retract the peritoneum. Superficial to the iliacus muscle, a thin layer of loose fatty tissue again becomes visible.

Step 10

The course of the DCIA is palpated in the groove formed by the transversus and iliacus muscle, and the iliacus muscle is sharply transected to the periosteum about 1–2 cm below the artery.

Step 11

Muscular detachment is continued at the ASIS, where the sartorius muscle is transected directly at its origin from the bone. The vascular pedicle, which is enveloped in the fascia between the iliacus and transversus muscle, must be carefully protected in the region of the ASIS when transecting the muscles.

Step 12

Osteotomy begins distally at the iliac crest after transection of the abdominal muscles covering the bone. The oscillating saw cuts through the inner and outer cortical bone until the desired depth of bone segment is reached. While doing this, the soft tissues are retracted with broad hooks to protect the peritoneum and to visualize the blade during the osteotomy. The vascular pedicle is transected and ligated at the distal osteotomy.

Step 13

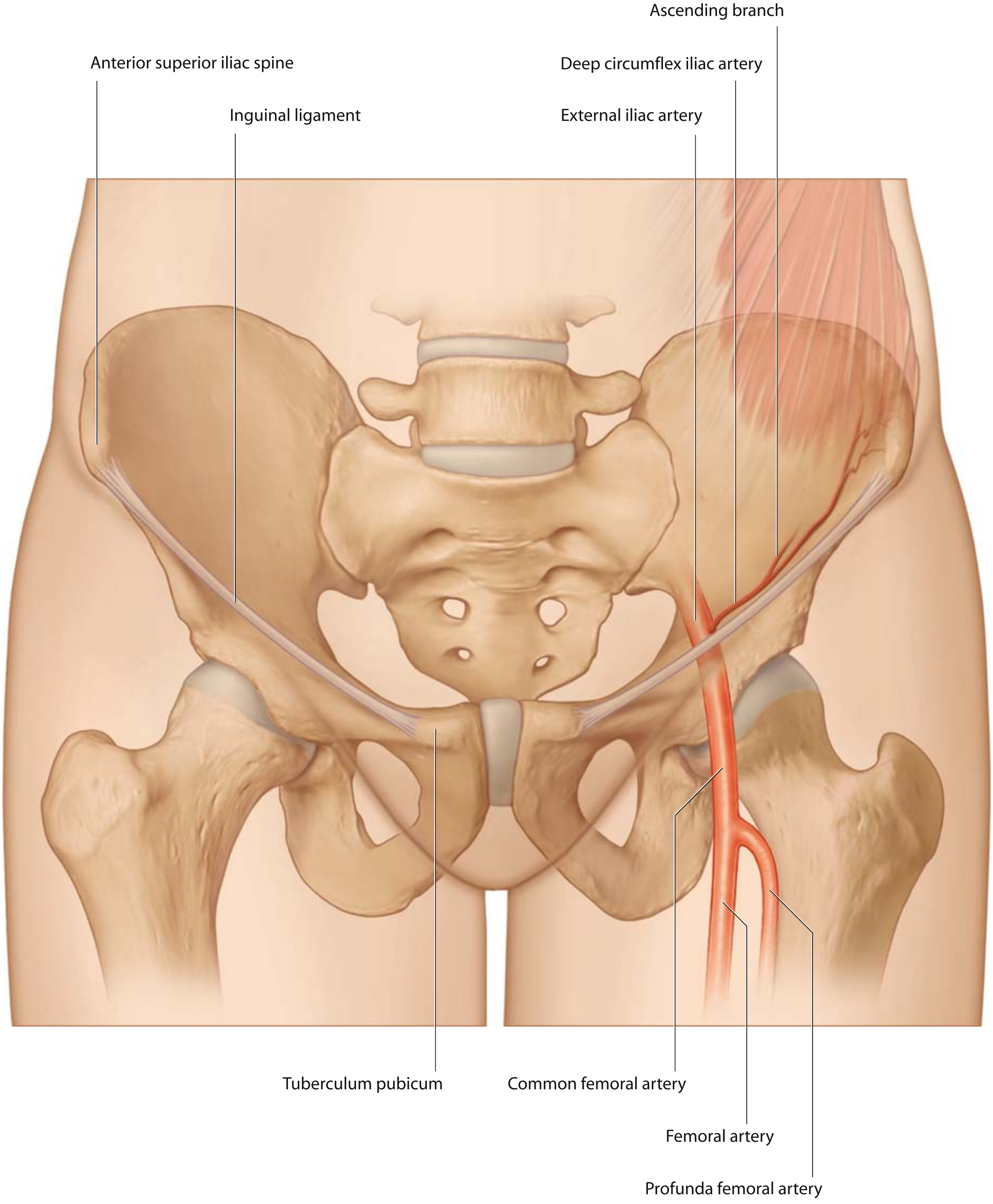
Osteotomy is continued by cutting the bone bicortically in an anterior direction, keeping a parallel distance from the upper rim of the iliac crest. The oscillating saw is inserted caudally enough at the lateral aspect of the pelvis that the vascular pedicle cannot be injured when penetrating the inner cortical layer. If a mandibular angle and ramus has to be built, the osteotomy is continued parallel to the anterior rim of the pelvis up to a depth of 6–8 cm. Again, the vascular pedicle must be carefully protected during the osteotomy.

Step 14

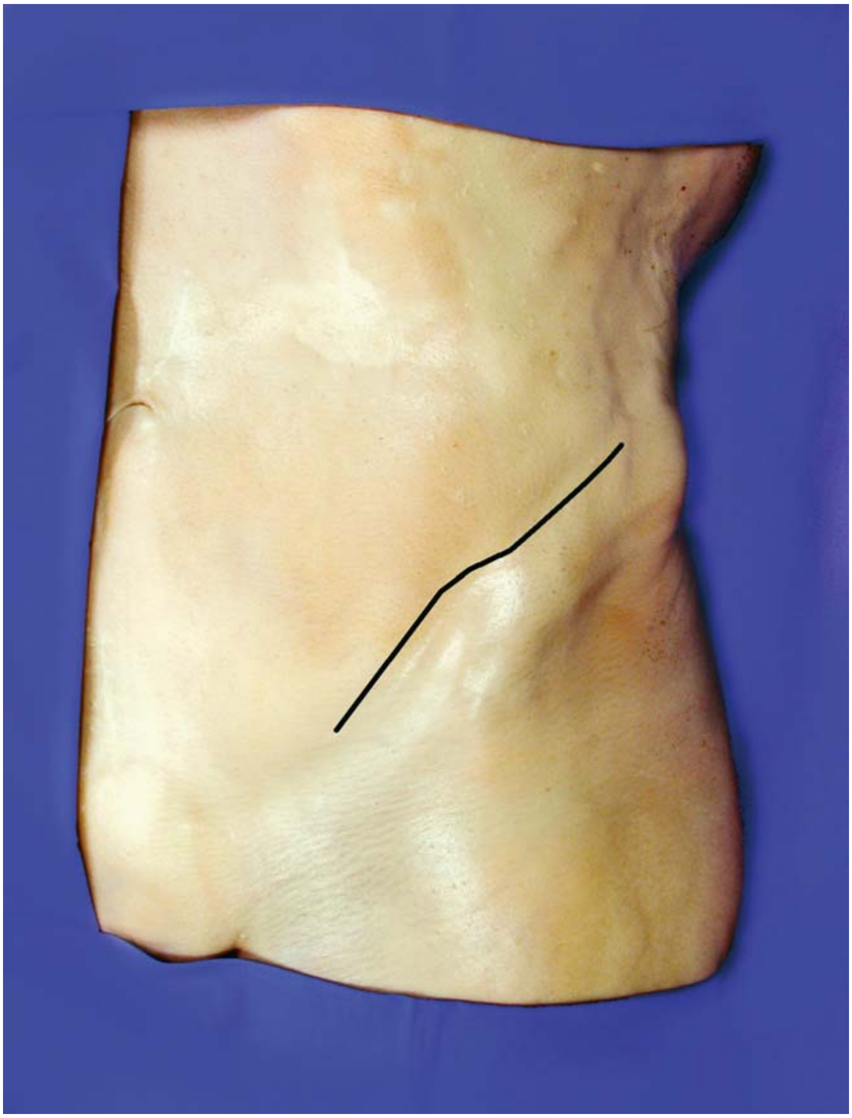
The osteotomized bone segment is elevated, and residual muscle fibers are transected. The vascular pedicle is dissected medially close to the external iliac vessels, the ascending branch is transected, and the artery is separated from the accompanying veins. The veins normally fuse 1–2 cm laterally to the external iliac vein.

Step 15

Perfusion of the flap is maintained until the recipient vessels are ready for anastomosis. Wound closure must be performed by an experienced surgeon after insertion of a deep drain and accurate hemostasis. Bone wax may be used at the cutting surfaces of the pelvic bone. First, the iliacus muscle is attached to the transversus muscle using multiple and deep sutures, which additionally can be placed through drill holes along the cut margin of the pelvic bone. Next, the internal and external oblique muscles are approximated to the tensor and gluteus muscles. Finally, the subcutaneous fatty tissue and the skin are closed in layers. The patient is immobilized for 3–4 days, and ambulation is then begun under physiotherapeutic assistance.



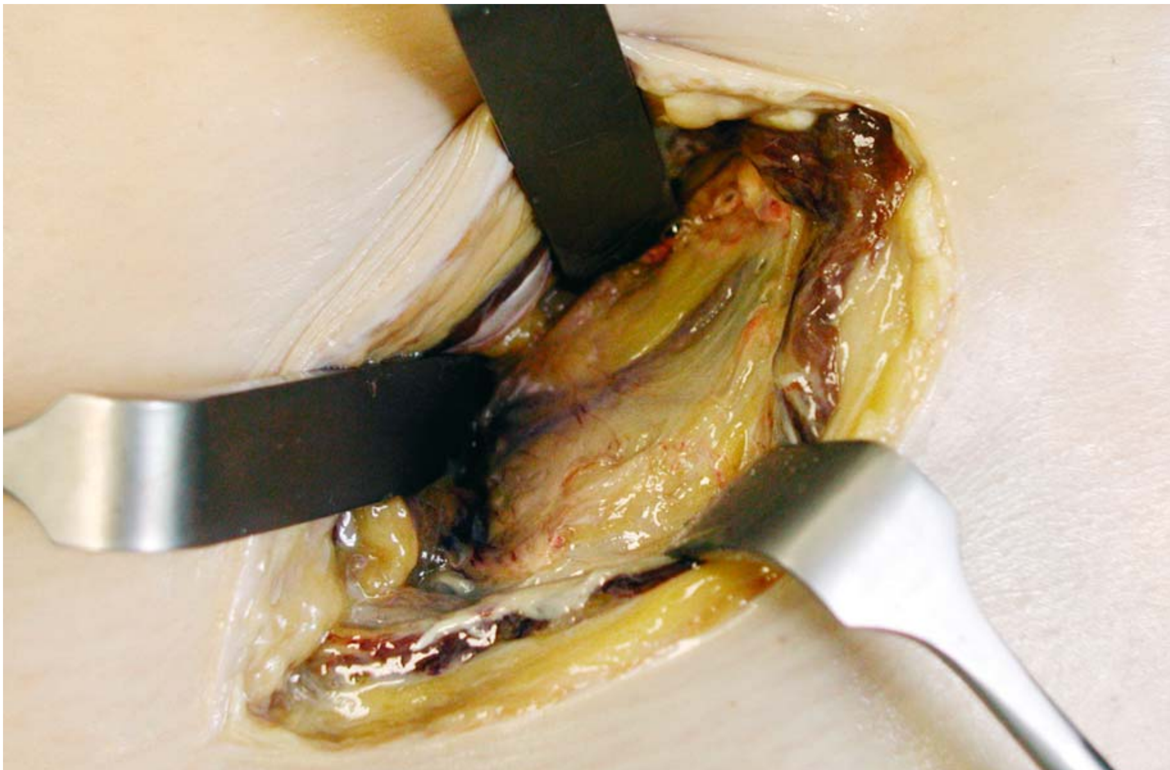
DCIA running along the inguinal ligament towards the inner lip of the iliac crest



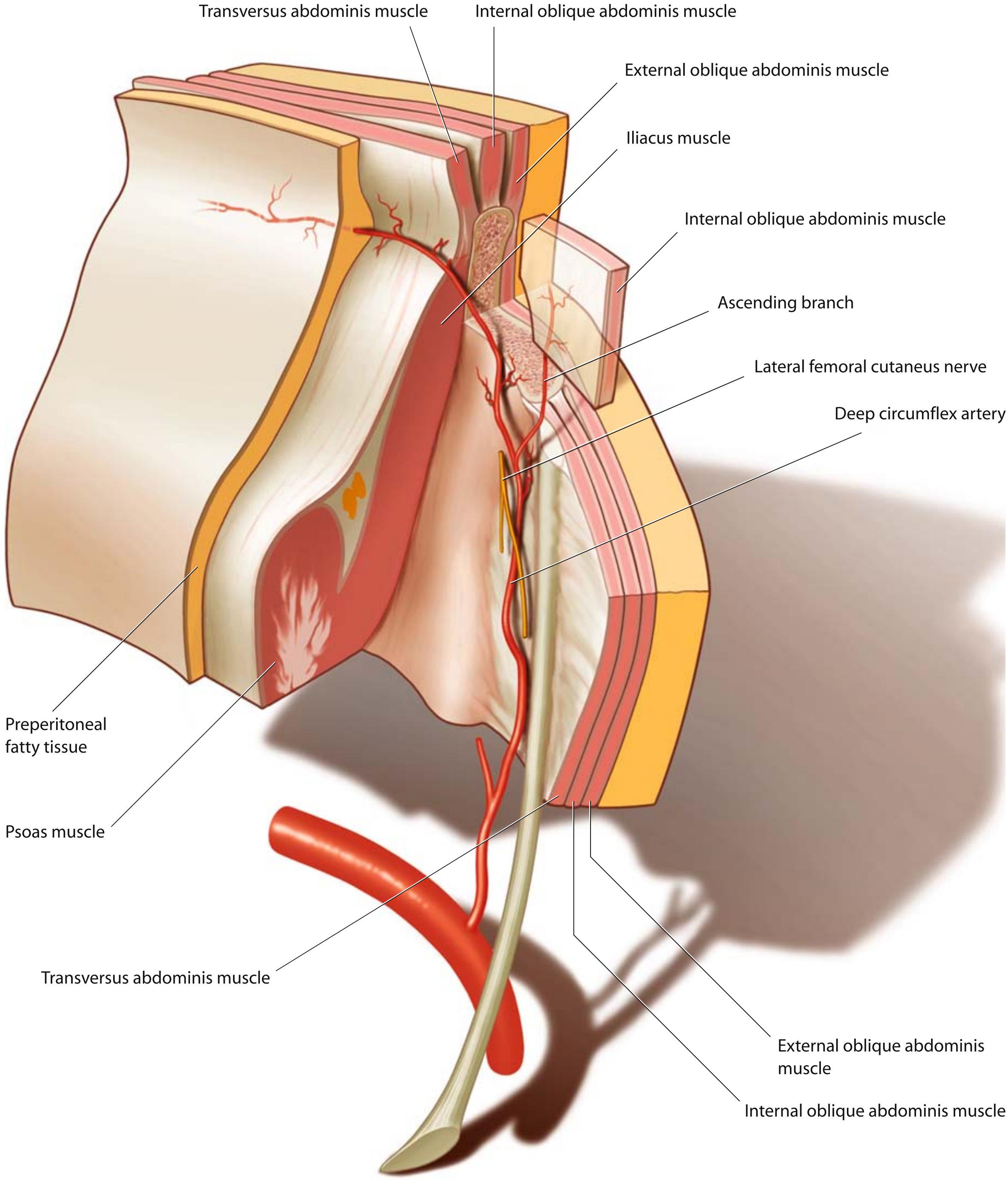
Step 1 • Orientation of skin incision for raising of myo-osseous iliac crest bone flaps

Step 2 • Skin incision, exposure of inguinal ligament

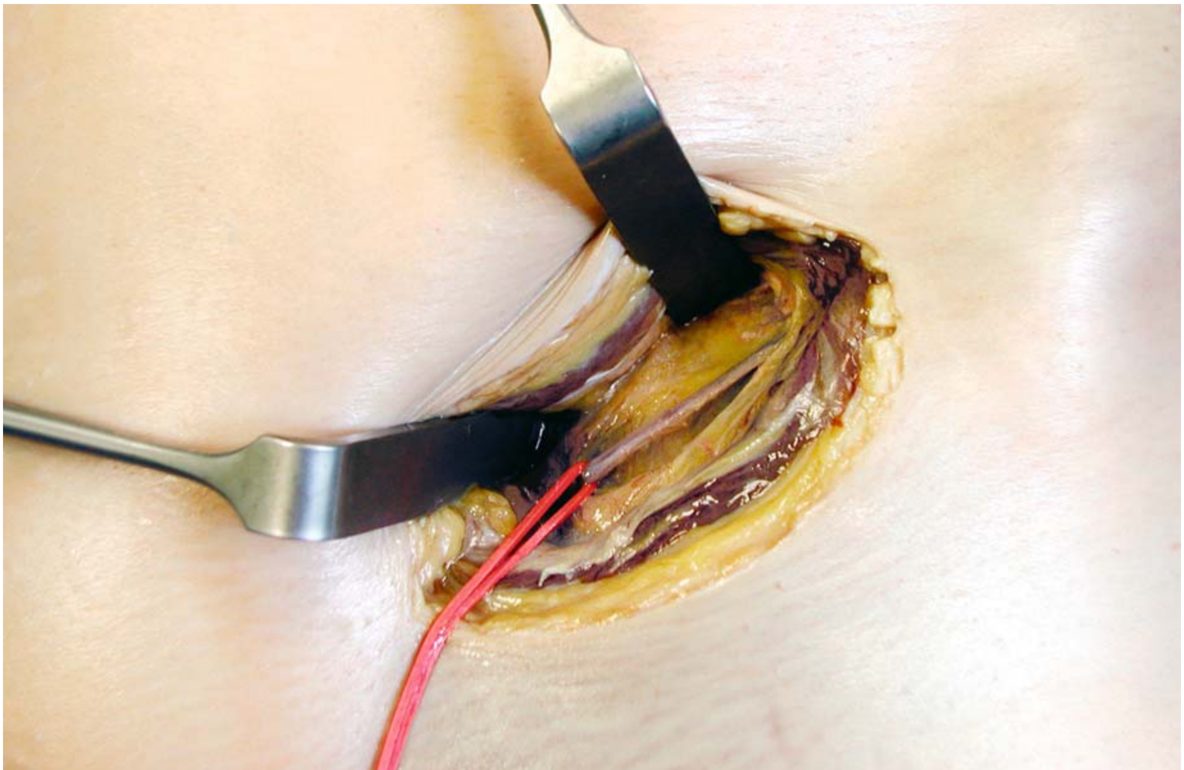
Step 3 • Identification of internal oblique muscle



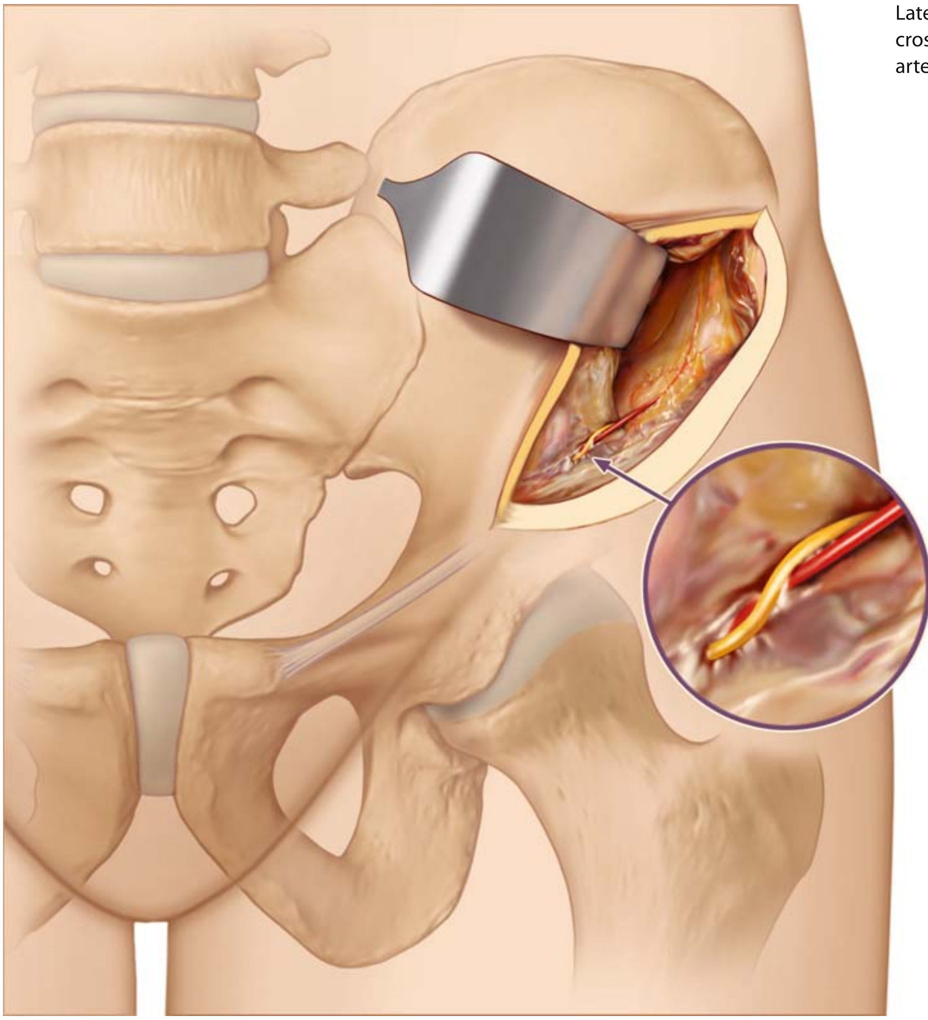
Step 4 • Exposure of vascular pedicle



Anatomy of the DCIA

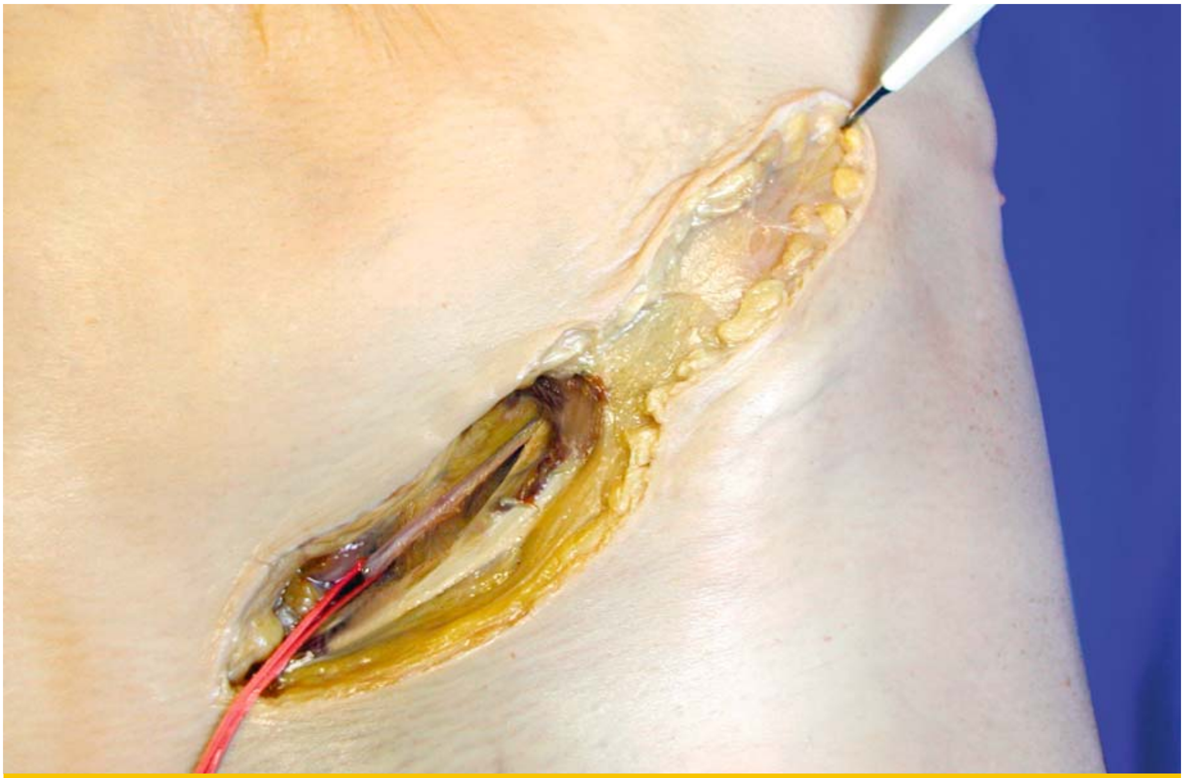


Step 5 • Dissection of DCIA towards ASIS



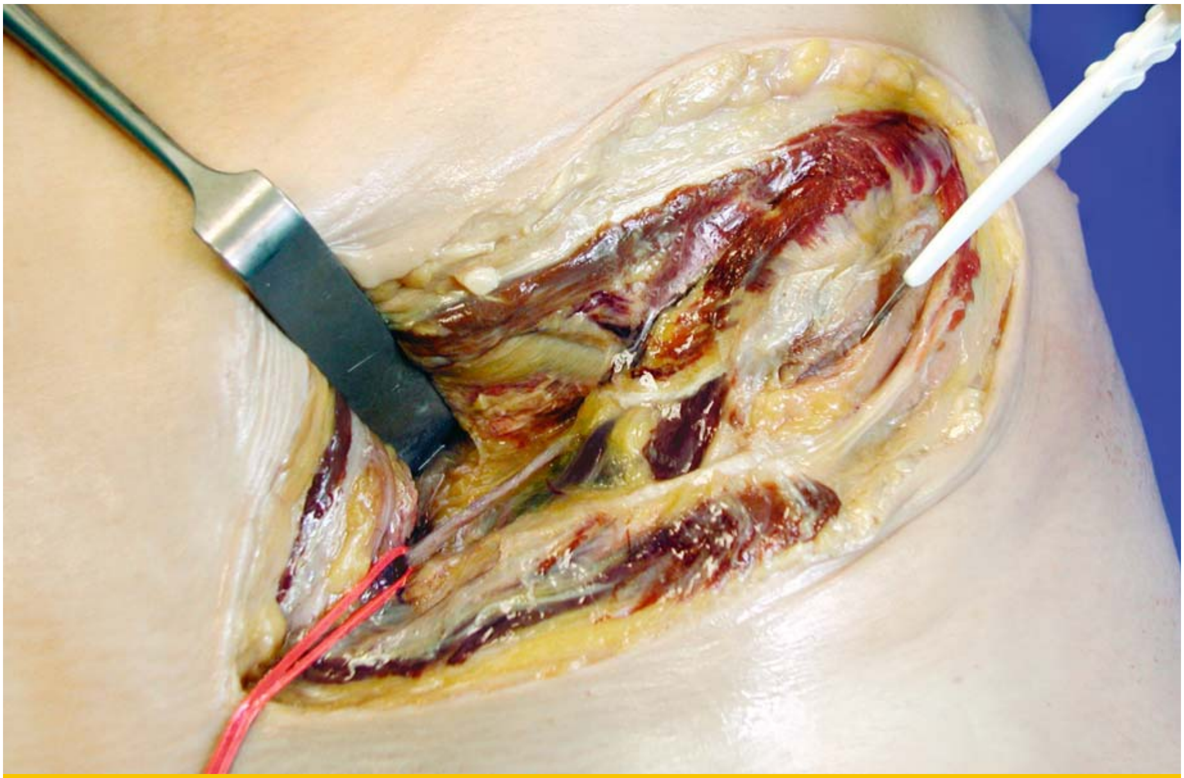
Lateral femoral cutaneous nerve crossing over deep circumflex iliac artery

Deep circumflex iliac artery

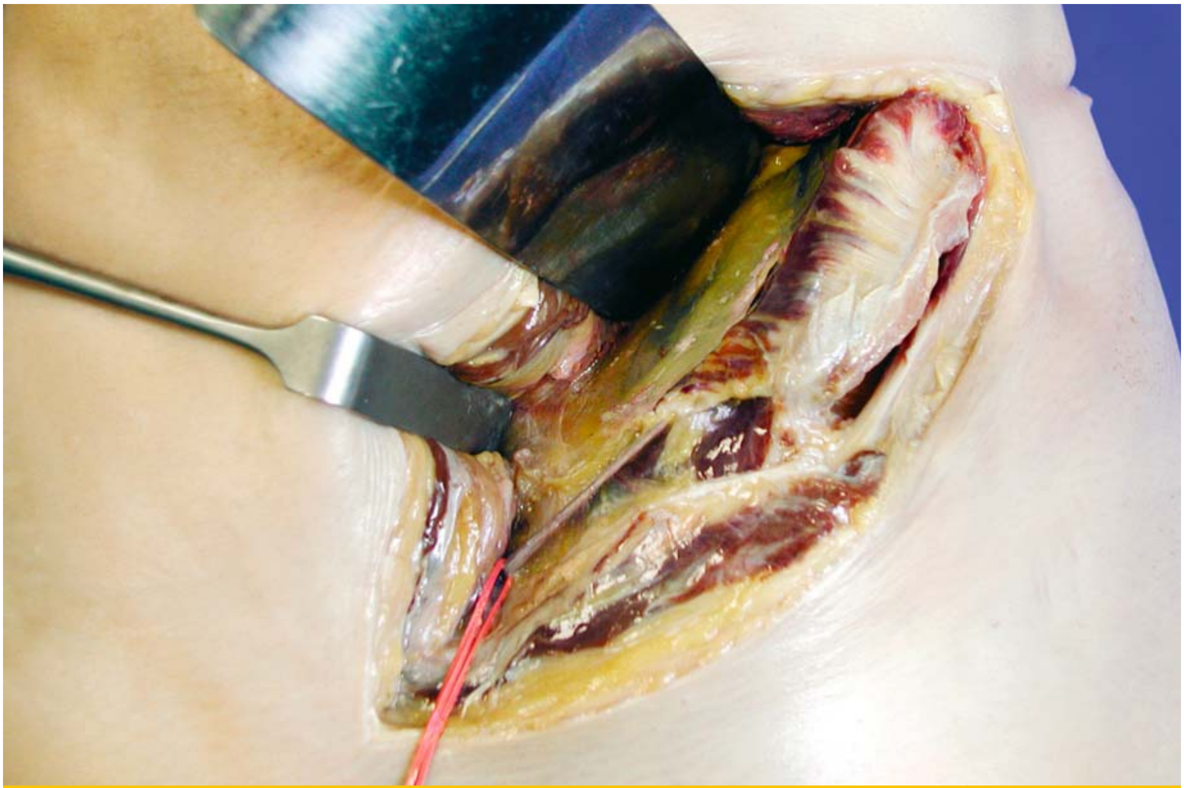


Step 6 • Skin incision along iliac crest

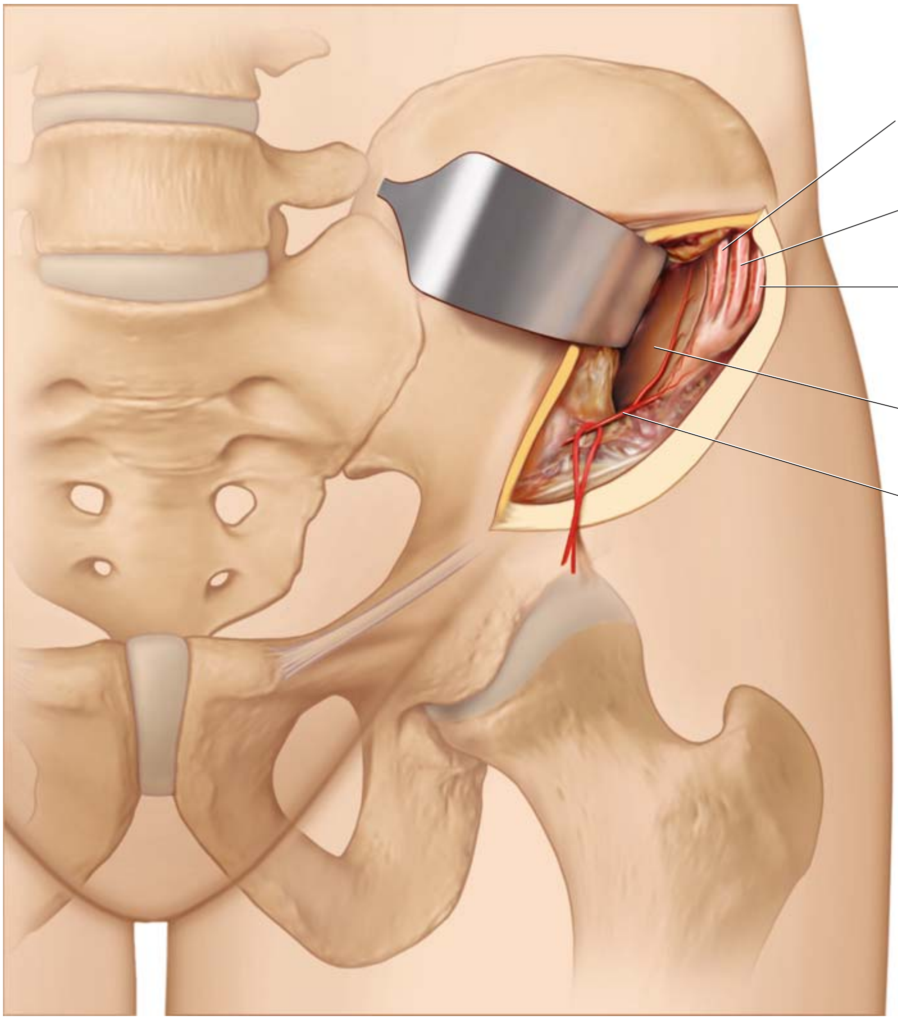
Step 7 • Transection of muscles at lateral rim of iliac crest



Step 8 • Detachment of muscles from gluteal surface of pelvis

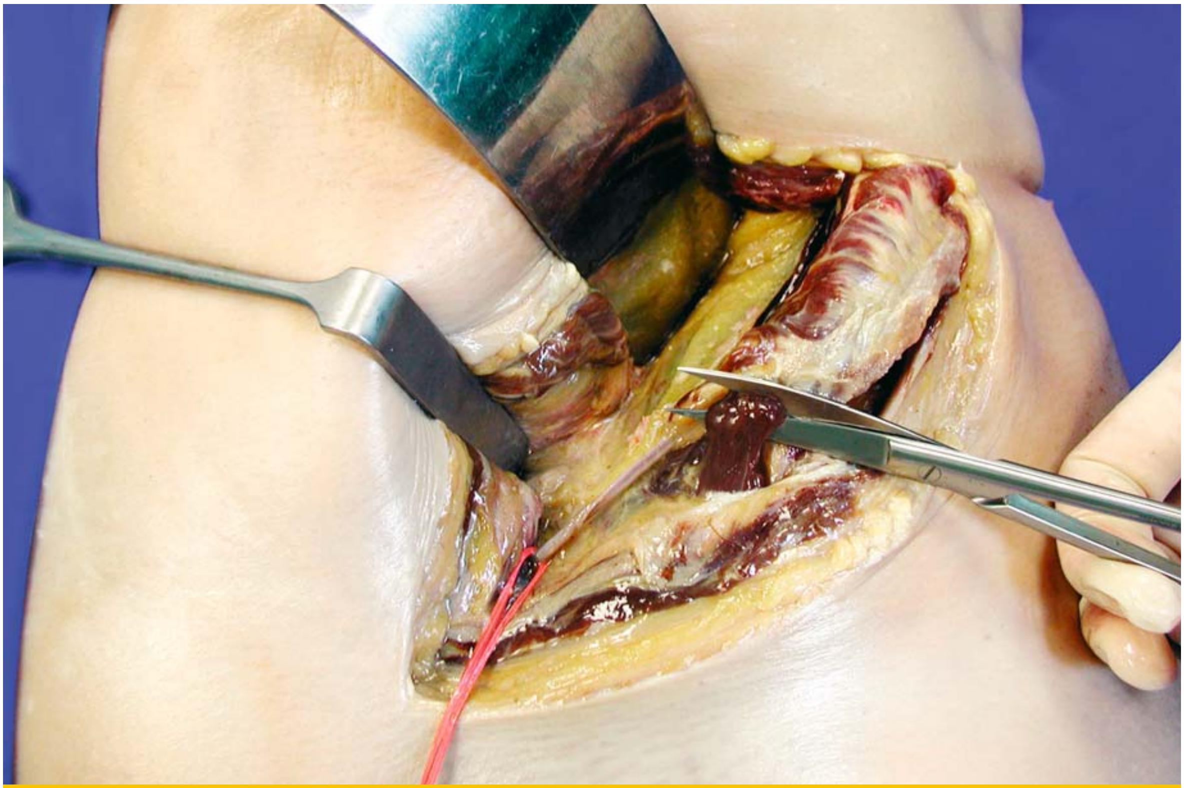


Step 9 • Transection of oblique abdominal muscles, exposure of iliacus muscle by retracting the peritoneum

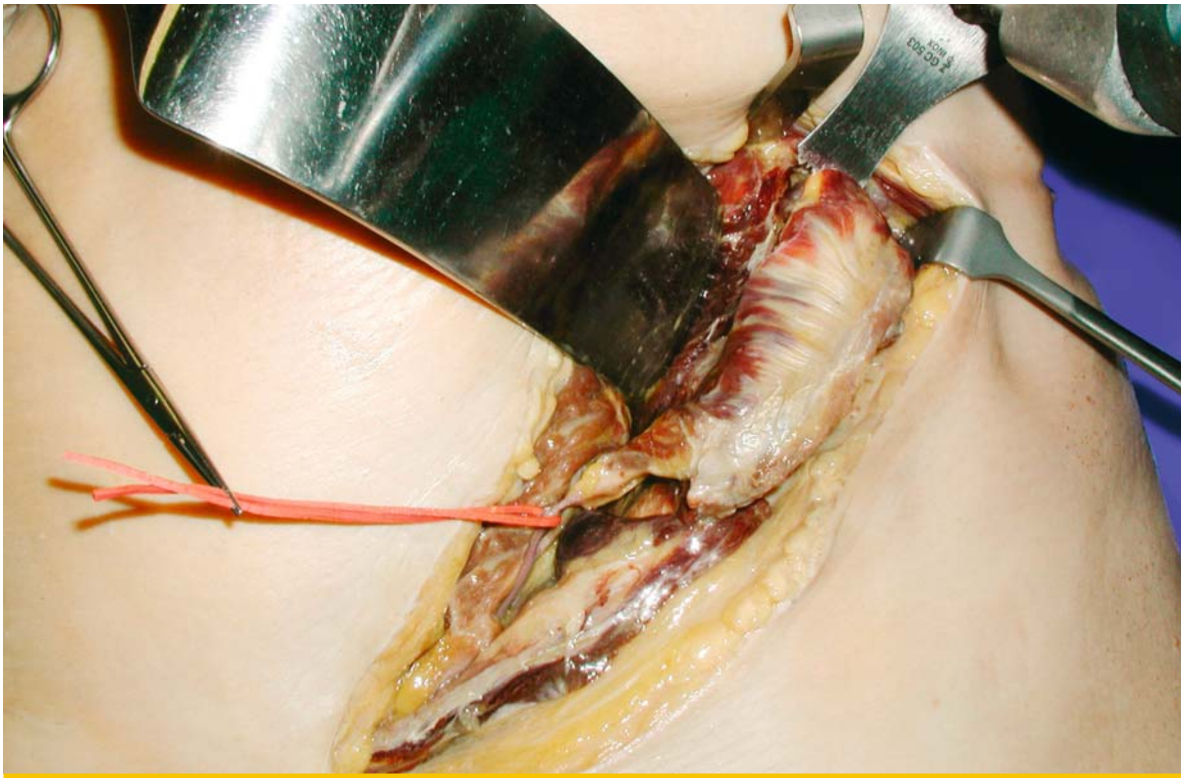


Exposure of inner aspect of pelvis showing the pedicle and iliacus muscle

Step 10 • Incision of iliacus muscle below DCIA

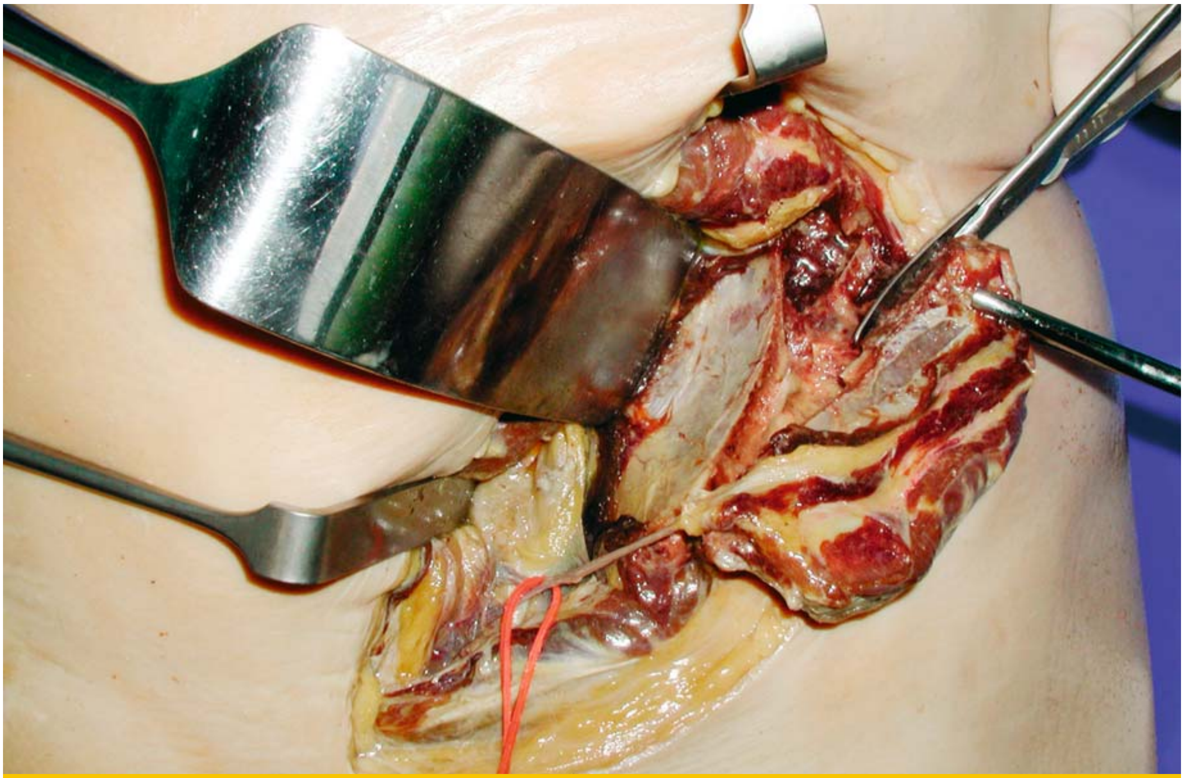


Step 11 • Transection of sartorius muscle at ASIS

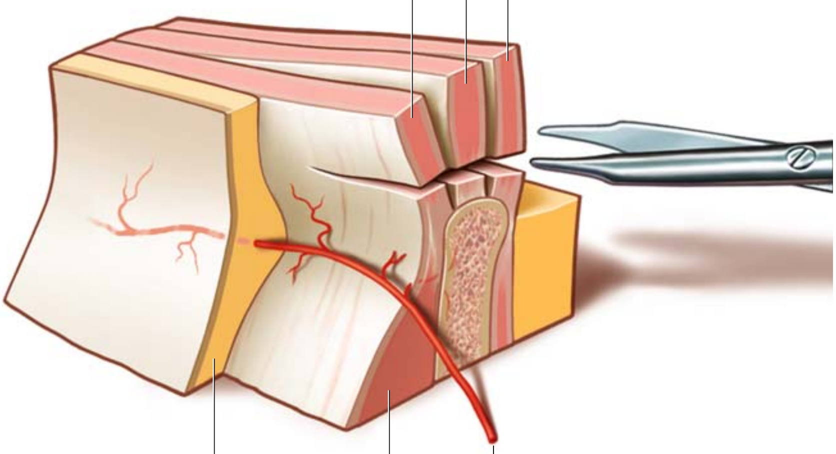


Step 12 • Distal osteotomy at iliac crest

Step 13 • Completion of osteotomy below the course of DCIA

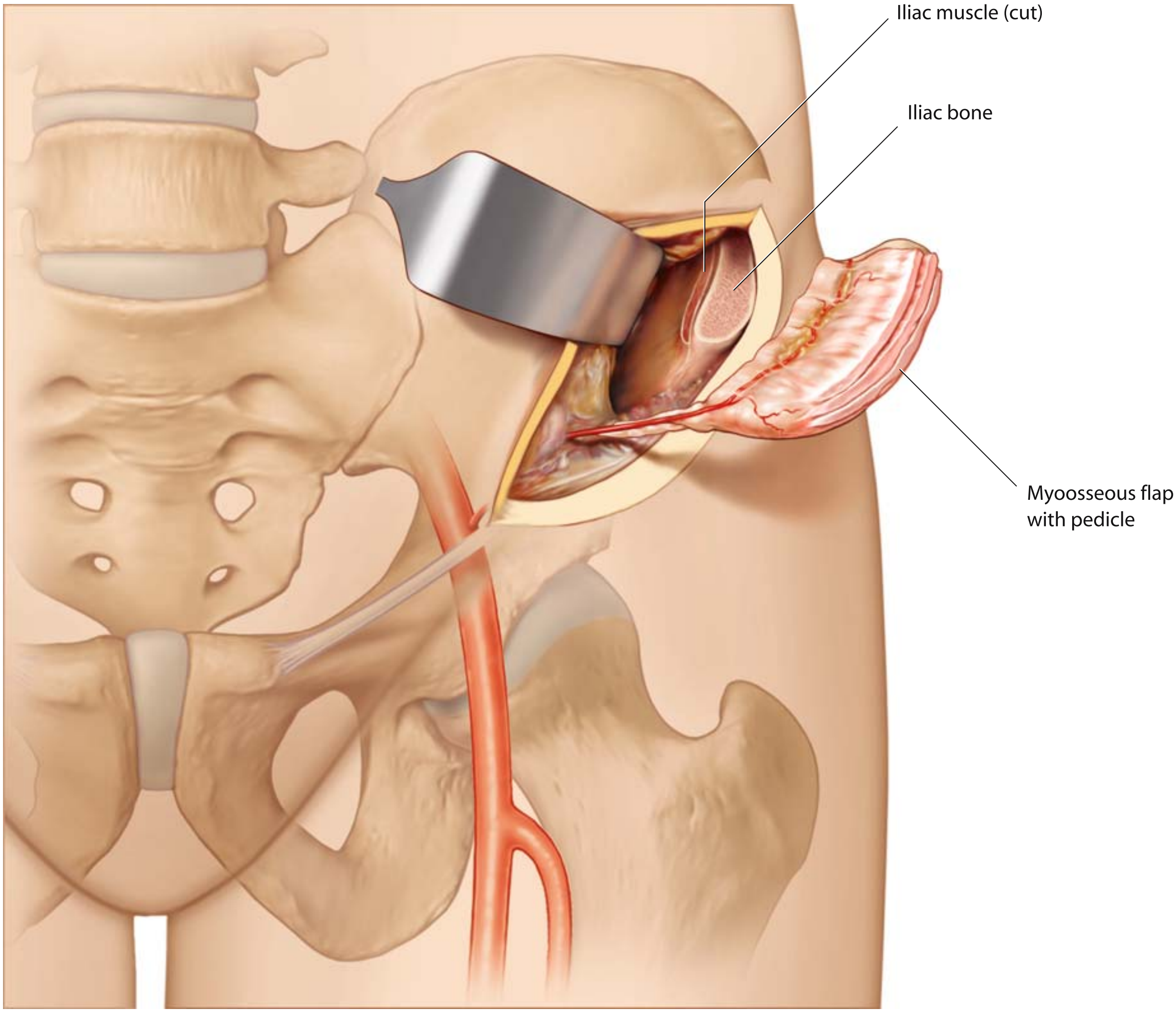


Step 14 • Transection and trimming of residual muscle fibers



Trimming of transversus and oblique muscles superior to DCIA

Step 15 • Myo-osseous iliac crest bone flap ready for microvascular transplantation



Flap perfusion is maintained until the recipient vessels are ready for anastomoses

Comments

Flap Design

For intraoral reconstruction, a skin paddle is only recommended in slim patients with significant and deep additional soft-tissue defects, because excess volume and bulk of the flap can lead to venous congestion of the skin paddle or functional discomfort to the patient. The skin paddle of the iliac crest osteocutaneous flap is more suitable for covering extraoral or perforating defects.

Step 1, 2: If the skin incision is performed caudal to the line between the pubic tubercle and the ASIS, the femoral trigonum will be opened, and the dissection will be performed caudal to the vascular pedicle. Additionally, motor branches of the femoral nerve might be injured.

Step 4, 5: After transection of the internal oblique muscle, the ascending branch of the DCIA might become visible first. This vessel may not be mistaken for the DCIA, but it will lead to the main artery, if followed in a proximal direction. After having identified the DCIA, the ascending branch should still be left intact for anatomical orientation. Furthermore, this will provide an opportunity to include parts of the internal oblique muscle for additional soft-tissue reconstruction.

Steps 6, 7: To facilitate the osteotomy, wide exposure of the operating field is necessary. Therefore, the skin incision should be at least 3 cm longer than the bone segment planned. If the hip is supported by a beanbag, access to the gluteal aspect of the pelvis is easier.

Step 8: Detachment of the gluteal muscles is best achieved using a sharp scalpel. The abdominal muscles can be bluntly undermined at the inner rim of the iliac crest, starting at the SIAS. Here, the DCIA can easily be followed as it courses along the undersurface of a muscle rim, which is formed by the iliacus and transversalis muscle.

Step 10: Before transection of the iliacus muscle and the inner periosteum of the pelvis, the pulse of the DCIA must be palpated. Keeping a muscle cuff is necessary for reliable perfusion of the bone flap.

Steps 12, 13: The whole osteotomy should be performed with the oscillating saw instead of chisels. To obtain a parallel curved bone segment at both sides, the caudal osteotomy must follow the natural curve of the iliac crest. This only can be achieved if the soft tissues have sufficiently been detached from the gluteal aspect of the pelvis.

Step 14: Bone wax should be used to stop the diffuse bleeding from the cutting surface of the pelvis. No bone wax should be applied to the bone flap at the osteosynthesis margins.

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Subject Index

Subject Index

… A

… B

… C

… D

… E

… F

… G

... H

... I

... J

... L

… M

… N

… O

… P

... Q

... R

... S

… T

… U