



# Orthoplastic approach to limb salvage surgery in oncology: types of flaps and surgical timing

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## Abstract

Extremities are a very common site for the development of malignant tumors. A multidisciplinary approach is essential for the proper management of extremity tumors, ensuring complete surgical resection with clear margins, proper management of tissue loss, and optimal functional recovery following reconstruction. Up to 95% of patients undergo successful limb-sparing treatments, avoiding amputation. We will discuss the advantages and disadvantages of using various flaps to reconstruct upper and lower extremities. We will also explore the applications of microvascular surgery and free flaps in this context and conclude with a reflection on the timing of reconstructions.

## Keywords

flaps, limb salvage, microsurgical reconstruction, oncology, orthoplastic approach

## Introduction

Soft tissue tumors (STS) are a heterogeneous class of mesenchymal tumors. They represent less than 1% of all malignant tumors in adults. The most common types of extremity STS in adults are undifferentiated pleomorphic sarcoma (previously known as malignant fibrous histiocytoma), liposarcoma, and synovial sarcoma. Despite the differences among the various histopathological subtypes, the majority of soft tissue sarcomas affect the extremities.<sup>[1]</sup>

Limb salvage surgery has become the gold standard in the treatment of bone and soft tissue sarcomas involving the extremities, with up to 95% of patients undergoing successful limb-sparing treatments, thus avoiding amputation. Treatment of these tumors requires adequate resection with wide margins (removal of the tumor along with at least a 2- to 3-cm surrounding margin of healthy tissue), combined with adjuvant therapy to achieve local control of

the disease. A multidisciplinary approach is essential for managing these patients and developing a successful reconstructive plan: the goal is not only to provide adequate soft tissue coverage, often requiring pedicled or free flaps, but also to restore form and function while minimizing donor site morbidity.

In the context of a multidisciplinary approach, some patients require adjuvant or neoadjuvant therapies to complete their diagnostic pathway, as we said. This eventuality must be taken into consideration because adjuvant therapies (both chemotherapy and radiotherapy) can lead to difficulties in surgical wound healing and flap integration, while the prothrombotic state of oncological patients worse by oncological therapy, may compromise the vascularization of the flap. Preoperative radiation along with chemotherapy alter the normal structure of the tissue inducing fibrosis and inelasticity of the surrounding skin and vessels, precluding the availability of local flaps. Adjuvant radiation

demands tissue with a stable vascularization to fill the defects, so when radiation is planned following surgery, skin grafts or muscle flaps covered with skin grafts are avoided due to their poor tolerance.<sup>[2]</sup>

Therefore, reconstructive surgeons face particular challenges, such as selecting the most appropriate flap and determining the optimal timing for coverage to avoid complications.

In this article, we describe some of the main flaps used in limb reconstructive surgery, based on data from the literature, with a focus on the use of free flaps, and address advantages and disadvantages of a one- or two-stage reconstructive approach.

## Extremities reconstruction

Extremities are a very common site for the development of malignant tumors. Fifteen percent of soft tissue tumors involve the upper extremities, while the lower extremities are affected at a 3:1 ratio in comparison with the upper extremities. A multidisciplinary approach is essential for the proper management of extremity tumors, ensuring complete surgical resection with clear margins, proper management of tissue loss, optimal functional recovery following reconstruction, and the administration of any potential neoadjuvant therapies with minimal risk of complications.<sup>[3]</sup>

The importance of achieving wide negative resection margins has been widely discussed in the literature, and it has a significant impact on both patient survival rates and local recurrence rates; according to the literature, it is around 20% in cases of inadequate resections.

Reconstructive surgery plays a pivotal role in the oncological patient's treatment plan following tumor resection, as it is essential to address the resulting defect. The characteristics and extent of the defect, along with the nature of the structures to be covered, will guide the selection of the appropriate reconstructive approach.

From these considerations, it is clear that meticulous planning is required before reconstructing a defect caused by the excision of an extremity tumor. Often, grafts and local flaps do not provide tissue stability sufficient to meet the reconstructive demands. Consequently, pedicled flaps based on a known vessel are more commonly employed, and in 11%–18% of cases, free flaps are necessary to address the specific needs of the reconstructive procedure.

The composition of the flap must also be considered in the reconstructive planning. In general, the fasciocutaneous flap has a cleavage plane on its deep surface, which is the fascia. Fasciocutaneous flaps, which have a cleavage plane on their deep surface known as the fascia, are particularly suitable for covering mobile structures such as tendons and joints, as the fascia does not adhere to underlying tissues. In contrast, muscular flaps, which adhere to underlying structures, improve the trophism of the recipient site through their independent vascular supply. These flaps are

especially effective for covering bone, as they help eliminate dead spaces and partially revascularize deep structures.

Neoadjuvant and adjuvant radiotherapies can also influence the surgeon's reconstructive decisions, as primary intention closures and grafts are less effective in irradiated tissue.<sup>[4]</sup>

Repair of limb defects with tension-free non radiated tissue is essential for favorable wound healing. If adjuvant therapy is recommended, fasciocutaneous or myocutaneous flaps provide durable coverage and will tolerate radiation therapy with less ulceration and wound complications.

Comorbidity conditions that affect wound healing must be carefully considered, requiring a detailed patient history and thorough preoperative physical examination of the lower extremities and potential tissue donor sites. Successful reconstruction requires attention to factors such as tobacco use, radiation exposure, diabetes, peripheral vascular disease, venous insufficiency, previous trauma or surgery, and any pre-existing infections or open wounds. These conditions significantly impact the quality of the tissue at the defect site and the wound healing capacity of both the recipient and donor tissues.

Unlike reconstructions of the trunk or scalp, limb reconstructions present unique challenges for the surgeon. These reconstructions must accommodate important functional requirements, such as joint movement at the knee or hand. Additionally, they must compensate for the loss of tendons, muscles, nerves, and bones sacrificed during tumor resection, provide stable coverage in areas where the skin is thin and soft tissues are poorly represented (such as the distal tibia), withstand load-bearing forces in the lower extremities, be pain-free, and address esthetic concerns, as these are highly visible areas.

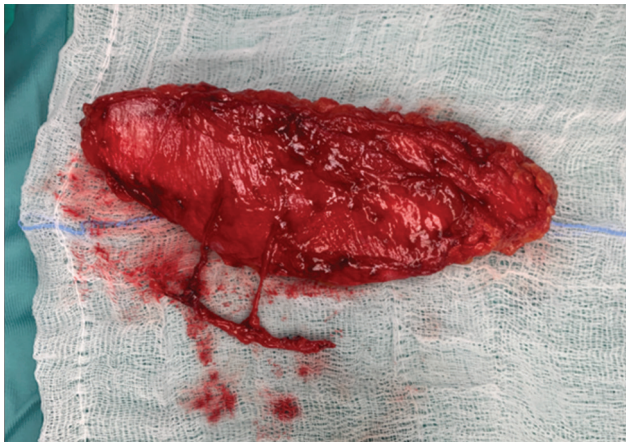
In the following sections, we will discuss the advantages and disadvantages of using various flaps to reconstruct the upper and lower extremities. We will also explore the applications of microvascular surgery and free flaps in this context and conclude with a reflection on the timing of reconstructions.

## The role of free flaps for limbs reconstruction

Free flaps play a crucial role in the reconstructive surgery of the limb following malignant tumor resection, particularly in cases of extensive soft tissue loss, inadequate local vascular supply, or complex defects. These flaps, which involve the transfer of tissue from a distant donor site with microsurgical anastomosis to recipient vessels in the defect area, provide reliable and robust coverage for large, deep, or irradiated wounds that cannot be adequately addressed by local or pedicled flaps.

Free tissue transfer can offer precise tissue matching (can be tailored to match the specific needs of the defect), both in terms of skin texture and functional requirements, ensuring optimal coverage for weight-bearing surfaces and

areas with complex anatomical features, such as the foot and ankle and hand, and accessible cosmetic restoration (Fig. 1).



**Figure 1.** Antero-lateral thigh (ALT) free flap.

While the technique is associated with prolonged surgical times, higher donor-site morbidity, and the need for advanced microsurgical skills, the outcomes of free flap reconstruction are generally favorable, with high success rates and low complication rates when performed by skilled teams.

Indeed, pedunculated flaps may be technically simpler but require a wider dissection, leading to a higher risk of hematomas, seromas, infections, and abscesses in the tumor resection area compared to that associated with the use of free flaps, as highlighted by Kapoor et al. in 2018, affecting also the functional outcome of the limb.

On the other hand, while providing excellent functional outcomes, the donor site of the free flaps may experience morbidity, including scarring, sensory loss, or functional impairment, depending on the tissue harvested; free flap

procedures are associated with a risk of complications, including flap failure, vascular thrombosis, and infection, and patients undergoing free flap reconstruction may experience longer recovery times, particularly if multiple sites or complex grafting procedures are involved. This can result in extended hospitalization, rehabilitation, and potential functional limitations in the immediate postoperative time.

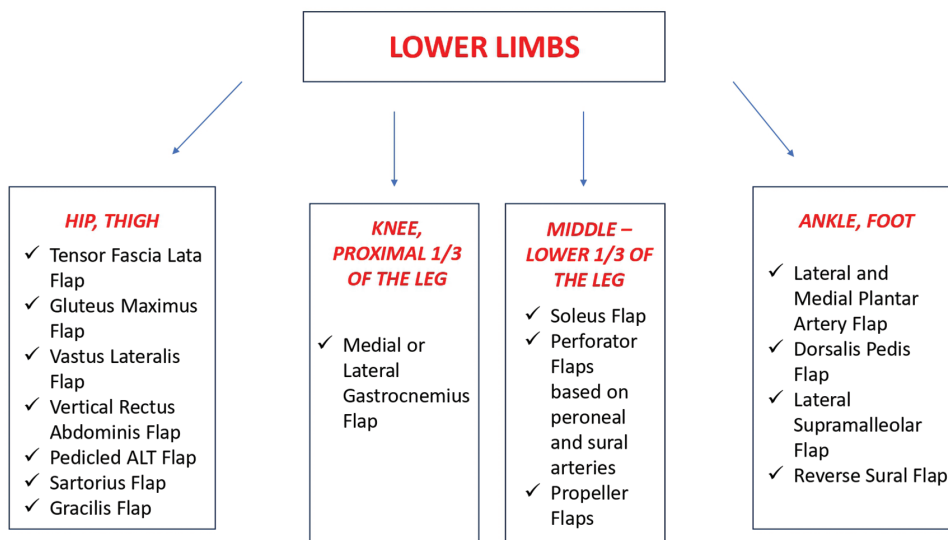
In cases where the local tissue has been irradiated or suffers from poor vascularity due to previous surgeries, free flaps provide a viable solution for coverage, ensuring a higher chance of graft survival.

Furthermore, the use of free flaps allows for the integration of additional procedures, such as nerve and bone grafting, to enhance functional recovery and improve the overall quality of life for patients following limb-sparing cancer surgery, making it a comprehensive approach to complex limb reconstruction.<sup>[5]</sup>

In summary, while free flaps offer significant advantages in the reconstruction of large and complex defects following malignant tumor resection, their use requires careful consideration of the patient’s overall health, the complexity of the defect, and the potential for donor-site morbidity and postoperative complications. Literature supports their efficacy in achieving optimal functional and esthetic outcomes but also highlights the importance of surgical expertise and a multidisciplinary approach to minimize risks and enhance patient recovery.

## Flaps for lower limbs reconstruction (Fig. 2)

The lower limb can be divided into six anatomical regions, as proposed by Topham et al.: the hip, thigh, knee, upper third of the leg, middle third of the leg, and foot and ankle. Each of these regions exhibits unique characteristics that require tailored reconstructive



**Figure 2.** Pedicled flaps for lower limbs reconstructions.

strategies.<sup>[6]</sup> We will focus on the most used reconstructive strategies for soft tissue defects in these regions.

- **Hip:** This area is particularly prone to soft tissue loss around bony prominences, such as the greater trochanter. Therefore, reconstruction must provide sufficient coverage for these structures: muscle flaps are often the most appropriate solutions.
- The **tensor fascia lata flap** is a reliable option for covering hip defects when the elements that form it have not been included in the resection or radiation field. It offers stable coverage but may impact on the function of hip and knee joint stabilizers after flap harvesting.<sup>[7]</sup>
- The **gluteus maximus flap** is another viable choice. Its technical ease of harvesting, robust vascular supply, and excellent elasticity make it an ideal option for hip reconstruction. Furthermore, it can maintain muscle function, as its origin, insertion, and innervation are preserved, as Ricciardi et al. reported.<sup>[8]</sup>

The **vastus lateralis flap**, due to its size and constant blood supply, is highly suitable for filling larger defects in the hip, even in patients with risk factors for wound complications. However, this flap may not be appropriate if the muscle is hypovascularized or denervated.<sup>[9]</sup>

The **vertical rectus abdominis musculocutaneous flap** can be used to cover trochanteric or groin defects. It may be especially useful in patients with hypotrophic or fibrotic muscles, such as the elderly. This flap helps to preserve the strength of the lower extremity, unlike many local flaps. However, its donor site incision can be less esthetic, and the skin paddle may be limited in size.<sup>[10]</sup>

The **free latissimus dorsi myocutaneous flap**, despite requiring microsurgical anastomosis and extended operating time, is an excellent choice for large substance loss or after failure of previous local flaps.

- **Thigh:** Upper thigh defects can be addressed using the **pedicled anterolateral thigh flap**, or muscle flaps such as the **sartorius and rectus femoris**, with subsequent skin grafting. The anterolateral thigh flap may also be considered for mid-thigh defects. The distal third of the thigh, however, poses a more challenging reconstructive challenge. Local muscle flaps, such as the **distal vastus lateralis and vastus medialis**, have been utilized as turnover flaps combined with skin grafting. These flaps, however, have limited rotation arcs and are not considered expendable due to the potential loss of leg extension. For more complex cases, the **anterolateral thigh flap** and **gracilis flap** can be harvested from the contralateral limb for free tissue transfer. Free flaps, including the **latissimus dorsi** and **rectus abdominis**, are good option for covering exposed bone, neurovascular bundles, or providing bulk in large composite resections.
- **Knee and proximal one-third of the leg:** The flexibility and limited skin laxity in this region complicate reconstruction. Colen et al. recommended a staged

approach, starting with local fasciocutaneous flaps, followed by muscle flaps, and finally free flaps. This approach has redefined the reconstructive algorithm for knee defect coverage.

- The **gastrocnemius flap**, either medial or sometimes lateral, is commonly used for covering exposed bone or joint capsules near the knee or the proximal leg.<sup>[11]</sup> When local flaps are insufficient, free flaps such as the **rectus abdominis, anterolateral thigh, or latissimus dorsi** with skin grafting are preferred due to their pliability and ability to allow complete joint function.<sup>[12]</sup>
- **Middle one-third of the leg:** Defects occurring in this location represent a very interesting challenge for the reconstructive surgeon due to the presence of very little subcutaneous tissue causing exposition of the periosteum, bones and tendons very easily. For smaller defects, less than 5 cm, local axial fasciocutaneous can be used.<sup>[13]</sup>

The peroneal artery perforator flap and the sural artery flap are also viable options for defects near these vessels.

The **soleus** as a local muscle flap represents a solid and reliable option for the reconstruction of the leg.<sup>[14]</sup> However, its utility may be limited by individual variability in muscle morphology, making it most suitable for leaner patients in whom the flap can cover the entire leg, excluding the proximal and distal tibial epiphyses.

In addition, propeller flaps—local flaps based on perforator vessels—can be employed to cover tissue losses along the leg. These flaps are rotated up to 180 degrees, offering an effective technique with a high success rate, good cosmetic outcomes, minimal complications, and no functional impairment.<sup>[15]</sup>

For larger defects, free-tissue transfer is typically required. Muscle flaps with skin grafting, such as the rectus abdominis, latissimus dorsi, and thin anterolateral thigh flaps, are particularly effective for tibial coverage.

- **Lower one third of the leg:** The lower third of the leg presents one of the most difficult challenges in reconstructive surgery due to the limited availability of locoregional options. Galarza et al., collecting data for literature and from their experience, proposed a treatment algorithm for selecting the most appropriate technique for defects in this region.<sup>[15]</sup> Locoregional flaps, including perforator-based flaps such as the peroneal and sural artery flaps, are often the first choice for soft tissue reconstruction. Bipedicled flaps, random adjacent tissue rearrangement, and the soleus flap have also been described, although limitations such as pedicle length and arc of rotation may hinder their effectiveness for the reconstruction of this area. Free-tissue transfer is more commonly used. In smaller defects, the radial forearm, lateral arm, lateral thigh, or scapular flaps can be used.<sup>[16]</sup> In larger defects, the anterolateral thigh, rectus abdominis, and latissimus-free flaps are preferred. Failure rates and

overall complication rates for local flaps have been reported as 1%–7%, which is comparable to rates for free tissue transfer.

- **Foot and ankle:** The reconstructive demands of the foot and ankle overtakes those of the proximal lower extremity due to the need for thin, sensate, and durable coverage for weight-bearing activities. Limited local flap options are available for the foot. Heel defects can be addressed with **lateral or medial plantar artery flaps**, providing sensate coverage with globous skin. The **dorsalis pedis flap** is an option for covering the medial and lateral malleolus and the proximal ankle. However, both of these flaps require skin grafting at the donor site, and the dorsalis pedis flap is associated with high donor-site morbidity, including the potential exposure of dorsal tendons and poor cosmetic outcomes.

The **lateral supramalleolar flap** is a commonly used technique for covering major defects in the foot and ankle due to its extensive coverage of the dorsum of the foot, medial and lateral arches, and heel.<sup>[17]</sup> The **reverse sural artery neurocutaneous island flap** was first introduced by Masquelet et al. in 1992.<sup>[18]</sup> This distally-based flap is typically supplied by the median superficial sural artery which is frequently accompanied by the sural nerve. It has proven to be an effective solution for addressing large soft tissue defects in the heel and the region of the lateral malleolus. Free flaps may be indicated for defects greater than 30–35 cm<sup>2</sup>, areas with inadequate local blood flow (due to radiation, tumor resection, or peripheral vascular disease), or when additional procedures such as bone, nerve, or tendon grafting are necessary. While free flaps offer the advantage of large tissue volumes, they can result in bulky reconstructions, prolonged postoperative morbidity, and extended operative times, compromising weight bearing and shoe wearing.<sup>[19]</sup>

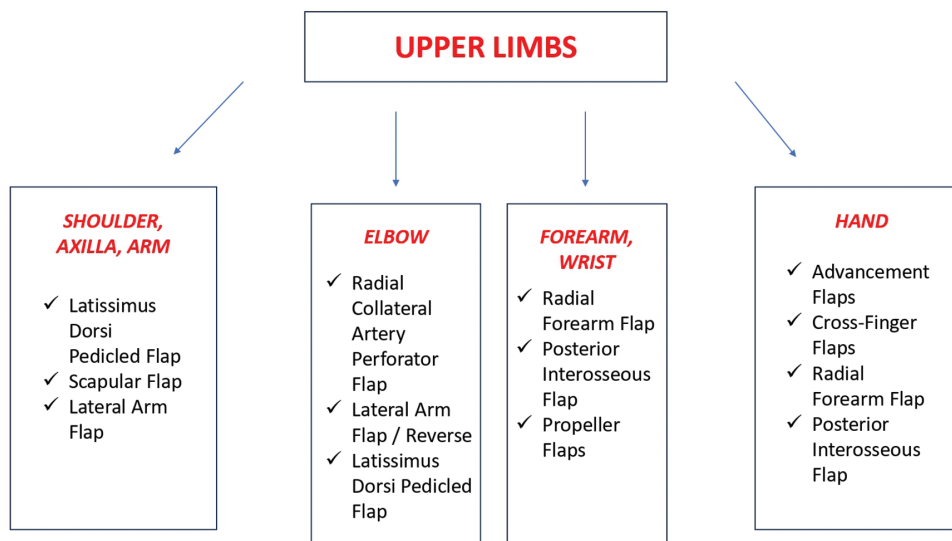
A viable alternative to bulky flaps is the **super-thin anterolateral thigh flap**. This flap’s reduced volume improves contour and pliability, making it ideal for distal extremity reconstructions. Its advantageous properties, such as improved tightening and reduced postoperative atrophy, make the super-thin ALT particularly suitable for plantar foot defects (**Fig. 3**).<sup>[20]</sup> Thin fasciocutaneous free flaps, such as the radial forearm, lateral arm, and lateral thigh flaps, work well for foot and ankle reconstructions due to their pliability and ability to provide local sensation when sensory nerves are accessible.



**Figure 3.** Free ALT used to treat a heel sarcoma.

### Flaps for upper limbs reconstruction (Fig. 4)

The surgical removal of soft tissue and bone sarcomas in the upper body often leads to significant tissue loss, neces-



**Figure 4.** Pedicled flaps for upper limbs reconstructions.

sitating advanced reconstructive techniques. Techniques such as pedicled and free flaps play a critical role also for upper limbs in providing durable coverage for defects and facilitating optimal rehabilitation, ultimately improving patient survival rates and quality of life.

Choosing the appropriate flap for reconstruction involves carefully considering factors such as the defect's location, size, and depth, as well as the need to restore function while minimizing complications at the donor site. This review provides a structured approach to reconstruction by categorizing the upper extremity into seven simplified anatomical regions: shoulder, axilla, arm, elbow, forearm, wrist, and hand. For each region, it explores flap options tailored to address the challenges posed by soft tissue and bone sarcoma resections, highlighting strategies to manage complex defects effectively.

## Shoulder, axilla and arm reconstruction

Reconstruction of the shoulder, axilla, and arm following oncological resections presents a complex challenge due to the anatomical and functional intricacies of these regions. The primary objective is to restore form and function while minimizing morbidity and ensuring durable coverage. Each of these areas presents unique challenges, from the extensive mobility of the shoulder to the critical neurovascular structures of the axilla and the structural and muscular requirements of the arm. A variety of flaps have been employed to address these needs, ranging from traditional pedicled flaps to advanced microsurgical options. Among the options for coverage flaps, a mention is due to the **latissimus dorsi flap**, which is widely used due to its versatility as evidenced by numerous scientific evidences.<sup>[21]</sup>

The **latissimus dorsi flap**, either pedicled or free, is widely considered the gold standard for large defects. The flap is vascularized by the thoracodorsal artery and vein, offering reliable perfusion and sufficient tissue to cover extensive resections (regarding skin and underlying muscular structures as the deltoid, trapezius and biceps) (Fig. 5). Arguello et al. evaluated its use in a cohort of 10 patients undergoing resections of the shoulder and upper arm. The study reported excellent functional outcomes. Minor wound complications occurred in 40% of cases, but no flap loss was observed. Despite these advantages, the latissimus dorsi flap has limitations, including potential donor site morbidity, such as reduced shoulder adduction and extension strength, particularly in active individuals.<sup>[22]</sup> As seen also in the systematic review by Lucatelli et al. alongside the use of the **latissimus dorsi flap**, either pedicled or free, other viable options for muscular restoration are represented by the **tensor fascia lata muscle autograft** and **medial gastrocnemius free flap** especially for deltoid replacement or reconstruction.<sup>[23]</sup> Considering shoulder reconstruction for larger composite defects, another option might be the **combined latissimus dorsi and scapular flap** which has proven its efficacy. Sakamoto et al. presented a case of a 76-year-old patient with a massive myxofibrosarcoma involving the shoulder, where the combined flap was used to reconstruct the defect. This approach achieved functional and aesthetic results while minimizing donor site morbidity by limiting the extent of latissimus dorsi harvesting. The integration of the **scapular flap**, based on the circumflex scapular artery, allows for additional pliable tissue, making it particularly suitable for posterior shoulder defects. However, these complex reconstructions require advanced surgical expertise and prolonged operative times.<sup>[24]</sup>

The arm, with its extensive muscular and vascular structures, requires flaps that can address both soft tis-



**Figure 5.** Pedicled latissimus dorsi flap used to cover a humeral megaprosthesis.

sue and structural deficits. The **anterolateral thigh flap** is among the most commonly used pedicled flaps for arm reconstruction, particularly for large defects. This flap provides a substantial amount of well-vascularized soft tissue and can be customized to include muscle or nerve components as needed. Alternatives include the **circumflex scapular artery perforator flap**, valued for its thin profile, long pedicle, and potential for chimeric designs, though further studies are needed to validate its applications. For larger defects, the **rectus abdominis muscle** or **myocutaneous free flap** is effective, with initial bulkiness that resolves over time, although rare donor site complications like hernias may occur. For moderate-sized defects, the **lateral arm flap** is frequently employed. This pedicled flap, based on the posterior radial collateral artery, provides thin, pliable tissue with minimal donor site morbidity. It is particularly suitable for covering defects in the mid to proximal arm.

## Elbow reconstruction

The elbow presents unique challenges in reconstruction due to the need to preserve mobility and protect exposed bony and neurovascular structures. Soft tissue coverage at the elbow often requires thin but durable flaps to withstand flexion and extension movements without causing joint restriction. The **lateral arm flap** as seen in arm reconstruction is employed for elbow reconstruction due to its proximity and reliable vascular anatomy.

The vascular anatomy of the lateral arm region facilitates the use of a 'reverse lateral arm flap' configuration. Tung et al. demonstrated the versatility of this approach in a study involving seven patients, where reversed lateral arm flaps were effectively utilized to provide soft tissue coverage for elbow defects. All the flaps were successful, with no losses reported, and by the six-month follow-up, all patients had regained full range of motion in their elbow joints, demonstrating both the effectiveness and functional benefits of the procedure. Many techniques described above as **the anterolateral thigh flap**, **circumflex scapular artery perforator pedicled flap**, **the rectus abdominis muscle** or **myocutaneous free flap** are viable options in the reconstruction of the elbow and forearm region. When the biceps muscle is extensively resected, functional restoration of elbow flexion can be effectively achieved using a **myocutaneous gracilis** or **medial gastrocnemius free flap**. Both flaps have demonstrated reliability in restoring flexion strength and improving overall upper limb functionality. The **radial collateral artery perforator flap** represents an alternative for posterior elbow defects. A case study described by Pinto et al. highlighted its utility in a 77-year-old patient undergoing reconstruction following a sarcoma excision. The flap, harvested with precise identification of perforators, allowed for effective coverage of exposed olecranon bone without complications during a 25-month follow-up.<sup>[25]</sup> For extensive elbow defects, as

also mentioned in the previous paragraph, the **pedicled latissimus dorsi flap** remains a robust option. This flap provides a substantial volume of tissue, offering both soft tissue coverage and the possibility of functional restoration. Pinto et al. reported the case of an 89-year-old patient suffering from recurrence of sarcoma of the elbow, with extensive scar retraction and elbow stiffness after a previous surgical treatment and sequential adjuvant radiotherapy. The **pedicled latissimus dorsi flap** successfully covered the new wider surgical defect and improved the range of motion following prosthetic joint replacement.<sup>[25]</sup> Another reconstructive option is the use of a fascia lata autograft, which has demonstrated effectiveness in restoring elbow extension after sarcoma resection. Clancy et al. reported a case where a strip of fascia lata was used to reconstruct the triceps insertion in a patient with a soft tissue sarcoma of the distal arm.<sup>[26]</sup>

## Forearm and wrist reconstruction

Reconstruction of the forearm and wrist following oncological resections requires a tailored approach to address defects involving critical structures such as tendons, nerves, vessels, and bones. Various flap options are employed.

The **radial forearm flap**, which has historically been the mainstay of forearm reconstruction, remains a reliable option for smaller defects due to its thin, pliable tissue and robust vascularity. However, its use has declined over time due to concerns about donor site morbidity, including the sacrifice of the radial artery and the esthetic impact of the donor site. For more extensive or composite defects, the **anterolateral thigh flap** has become a widely favored alternative. This free flap offers versatility with its large, vascularized surface area, and the ability to be harvested as a fasciocutaneous or myocutaneous flap.<sup>[27]</sup>

Reconstructing the wrist often involves complex defects with exposed tendons, bones, or neurovascular bundles, requiring solutions that maintain both form and function. For localized defects, **propeller flaps** based on perforators from the radial or ulnar arteries provide reliable and esthetically pleasing coverage. These flaps are particularly suited for defects at the distal forearm or wrist and involve minimal donor site morbidity.<sup>[28]</sup>

For more extensive wrist defects, free flaps such as the **thoracodorsal artery perforator flap** and the **myocutaneous anterolateral thigh flap** are frequently employed. The thoracodorsal artery perforator flap offers a large surface area for coverage and can be harvested with a hidden scar, improving cosmetic outcomes. Its versatility and ability to adapt to varying defect sizes make it an important choice for complex reconstructions. Similarly, the myocutaneous anterolateral thigh flap provides both soft tissue and functional tendon restoration.

Emerging techniques in forearm and wrist reconstruction include composite and chimeric flaps, which combine muscle, tendon, and skin components into a single flap.

## Hand reconstruction

Reconstructing the hand following oncological resections presents unique challenges due to the intricate anatomy and the proximity of critical structures.

Local flaps remain a pillar for addressing small to moderate defects. Techniques such as **advancement flaps**, **cross-finger flaps**, and the **Moberg volar advancement flap** are frequently employed for defects involving the volar or dorsal aspects of the hand. The Moberg flap, for example, is particularly effective in reconstructing thumb defects, providing pliable, gliding skin that closely matches the texture and function of the original tissue. However, local flaps are generally limited in their applicability for larger defects or those involving multiple anatomical components.<sup>[23]</sup>

For larger defects, regional flaps such as the **radial forearm flap** and the **posterior interosseous artery flap** have historically played a significant role. The **radial forearm flap** is a versatile option that provides thin, pliable tissue and robust vascularization, making it suitable for dorsal and volar defects (**Fig. 6**). However, donor site morbidity, including radial artery sacrifice, has limited its use in modern practice. The **posterior interosseous artery flap**, on the other hand, is an excellent alternative for dorsal defects, sparing the major arterial supply and providing effective coverage for exposed tendons and bones. It offers a thinner, more pliable tissue ideal for maintaining hand mobility.

Free flaps have revolutionized the management of extensive hand defects by enabling complex reconstructions that



**Figure 6.** Radial forearm flap.

address composite tissue needs. The **anterolateral thigh flap** is among the most commonly used free flaps for hand reconstruction due to its large harvestable area, long pedicle, and ability to incorporate various tissue components, including fascia and muscle. The anterolateral thigh flap has been used effectively in composite defects requiring simultaneous coverage and tendon reconstruction. Additionally, its inclusion of sensory nerves, such as the lateral femoral cutaneous nerve, offers the potential for sensory reinnervation, enhancing functional outcomes.

Other free flap options include the **groin flap** (based on the superficial circumflex iliac artery), which remains a reliable choice for covering large defects, particularly in settings with limited resources. However, its short pedicle and limited versatility can make it less suitable for complex reconstructions.

For thumb reconstruction, specific techniques such as the **temporoparietal fascia flap** or the **anterolateral thigh fascial flap** provide thin, pliable tissue that facilitates mobility and maintains hand function.

In oncological hand reconstruction, managing sarcoma defects requires advanced planning and precise execution. A study by Labow et al. emphasized the importance of reconstructive strategies tailored to individual cases, noting that free flaps, including the radial forearm flap and iliac crest-based flaps, were effectively employed in sarcoma patients to achieve functional preservation and esthetic outcomes. Despite high rates of postoperative complications, such as radiation-induced tissue damage, the functional outcomes remained favorable.<sup>[29]</sup>

Hand reconstruction, particularly following sarcoma resections, often involves multidisciplinary collaboration. Communication between oncologists, surgeons, and rehabilitation specialists is critical to achieving optimal outcomes. The integration of advanced techniques, such as composite free flaps and nerve-integrated reconstructions, continues to expand the possibilities for restoring function and esthetics in even the most complex cases. While local and regional flaps provide reliable solutions for smaller defects, free flaps remain indispensable for addressing extensive or composite reconstructions.<sup>[23]</sup>

## Timing of reconstruction

The correct orthoplastic reconstruction timing in orthopedic oncology remains a debated topic. While orthoplastic reconstruction is highly recommended in the first 72 hours in the event of trauma, in oncology there is no univocal position on the topic. In fact, there are two strategies: one-stage (early) or two-stage (delayed) reconstruction (**Fig. 7**). In case of early reconstruction, tumor resection and free or local flap reconstruction are performed in the same surgical session. This choice has the advantage of immediately managing the loss of substance, also allowing access to therapies such as chemotherapy and radiotherapy in a short time. Furthermore, microsurgical anastomoses are certainly eas-



**Figure 7.** Delayed reconstruction after resection of a forearm's sarcoma.

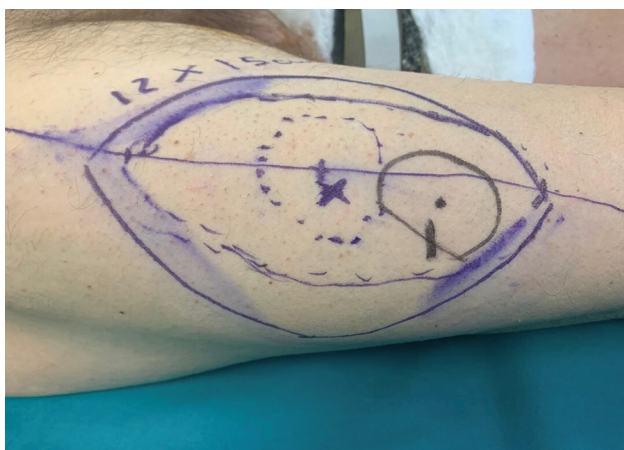
ier to perform given the better soft tissues conditions and the absence of scar. But it also has disadvantages: it is not the best solution in case of uncertain diagnosis or doubtful margins. The two-stage or delayed reconstruction has the undoubted advantage of being able to perform an orthoplastic reconstruction after careful histological study that has excluded the persistence of neoplasia or the need to widen the margins, but on the other hand it has undoubted disadvantages such as the presence of abundant scar tissue, the compromise of the recipient vessels in the case of free flap, the need to resort to temporary coverage. As regards the latter, in the literature we find different strategies: negative pressure dressings or double-layer dermal substitutes.<sup>[30]</sup> In particular, these systems allow to gain the time necessary to complete the oncological evaluation or to perform pre-reconstruction brachytherapy in particular associated with Vac-therapy. The use of the double-layer dermal substitute is of proven use for the treatment of malignant skin tumors, but there are also cases reported in which it was used as a temporary coverage before the definitive reconstruction in limbs.<sup>[29]</sup> Several authors, such as Wu et al., have shown that flap reconstruction exposes the patient to a lower risk of complications even compared to primary intention closure, as flap reconstruction is burdened by a lower risk of wound complications at 90 days, but early reconstructions are associated to increased surgical times and prolonged hospitalization.<sup>[31]</sup> Clinical and functional results in the literature are mainly in favor of primary flap. Zhou et al. reported 28% of complications in the early reconstruction group and 100% in delayed reconstructions. Although in line with the literature data, we believe that this study shows a clear selection bias as well as a numerical

imbalance between the two groups compared. The authors themselves declare that the delayed reconstruction group consisted of only 7 cases (32 cases in the early group) and that these represented the most complex ones compared to the other group.<sup>[32]</sup> On the other hand, other authors emphasize the need for a delayed approach in case of doubtful margins. Lawrence et al. reports shorter operating times for single procedures and less need for prolonged observations in intensive care.<sup>[33]</sup> On the other hand, the very recent study by Haldeman et al. did not highlight such significant differences between the two strategies, focusing on the centrality of the patient and the need for multidisciplinary assessments in consideration of the complexity of malignant tumors of the limbs and the different behavior of the various oncological pathologies to be treated.<sup>[34]</sup> In conclusion, early reconstruction is to be preferred whenever possible, after careful evaluation of the patient and his oncological disease. While, on the one hand, it will be necessary to carefully evaluate from an anesthesiologic point of view whether the patient can sustain prolonged surgical procedures, on the other hand, early reconstruction is practicable only if the neoplasia has been carefully studied and the margins are free from disease, for example, by confirming it with an intraoperative extemporaneous histology.<sup>[35]</sup>

### Size of defects

Bigger defects need free flaps to be covered, also in association with other techniques such as thin skin grafts. Local flaps are routinely performed to approach small and medium size defects. Defect size calculation is essential to cor-

rectly plan the reconstructive strategy. The flap is drawn in the shape of an ellipse considering the width of the defect and its height respectively (**Fig. 8**). Thickness of the flap is also measured using pinch calipers. The technique proposed by Hurley et al. is very interesting, as it also allows to estimate the desired volume of the flap, applied to the **gracilis flap**. On the assumption that flaps resemble two isosceles prisms, the volume formula of a prism was used to calculate the preoperative flap weights and then compared with the intraoperative results, obtaining a high correlation.<sup>[36]</sup>



**Figure 8.** Drawing of an ALT flap.

## Donor site complications

Flap harvest will occasionally lead to donor site complications. Most of these are treated easily without relevant esthetic or functional outcomes. Typical donor-site complications include hematoma, seroma, infection, and wound dehiscence. Muscular flaps could be associated with mild loss of strength and/or mobility of the involved limb, as happens in case of latissimus dorsi flap harvesting. A rare but dangerous complication of the radial forearm flap is the radial hand and/or thumb acute ischemia. Allen test is mandatory prior to proceeding to harvest this kind of flap. Patients who undergo the fibula flap can be commonly affected by complications. In fact, the overall donor-site complication rate has been reported at over 30%, due to wound healing and gait and musculoskeletal issues. The common harvested ALT flap could be associated with complications as well. The most common one is thigh numbness or paresthesia related to injury to the lateral femoral cutaneous nerve.<sup>[37]</sup> A more dangerous, but rare, complication is also described by Moon et al.: the thigh's compartment syndrome due to primary closure of the donor site after harvesting a big flap.<sup>[38]</sup>

## Flaps and chronic diseases

Arterial hypertension, type 2 diabetes mellitus, and atherosclerotic vascular disease are common vascular comor-

bidities, which may affect flaps outcomes. This because microvascular blood flow and tissue oxygenation could be compromised, causing reconstructive unsuccess. Tan et al. demonstrated in their systematic review how fibrotic vessels and atherosclerosis, commonly found in diabetic patients, may lead to flap loss or major post-operative complications.<sup>[39]</sup> Ozkan et al. demonstrated that the presence of chronic renal disease, especially in association with diabetes mellitus, increase the risk of flap loss.<sup>[40]</sup> Therefore, close blood glucose and blood pressure monitoring are essential before and after harvesting flap. In patients with poor compensation, it is mandatory to optimize therapy before performing any orthoplastic procedure. Furthermore, the use of dual anticoagulant/antiplatelet therapy is essential in the post-operative time for the first 3 weeks.

## Conclusions

The treatment's success is due to the correct evaluation of the surgical timing and the multidisciplinary approach. It is essential to know exactly the best flap to use for the site and type of soft tissue loss and the best techniques to perform it, including microsurgical ones. A meta-analysis on the topic could further confirm the data reported in the literature.

## Authors contribution

Conceptualization: G.M. and E.P.; methodology: M.S.; investigation: M.S., R.V., and O.E.; resources: M.C. and G.V.; writing original draft preparation: M.S., M.C., and G.V.; writing review and editing: M.C. and G.V.; supervision: E.P. All authors have read and agreed to the published version of the manuscript.

## Conflict of interest

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## References

1. Kunisada T, Nakata E, Fujiwara T, et al. Soft-tissue sarcoma in adolescents and young adults. *Int J Clin Oncol* 2023; 28(1):1–11. doi: 10.1007/s10147-022-02119-7

2. Abouarab MH, Salem IL, Degheidy MM, et al. Therapeutic options and postoperative wound complications after extremity soft tissue sarcoma resection and postoperative external beam radiotherapy. *Int Wound J* 2018; 15(1):148–58. doi: 10.1111/iwj.12851
3. LaValley MN, Dugue D, Diaddigo SE, et al. A systematic review of the orthoplastic approach in adult lower extremity soft tissue sarcoma flap reconstruction. *J Am Acad Orthop Surg Glob Res Rev* 2024; 8(3):e23.00290.
4. Pesare E, Vitiello R, Greco T, et al. Soft tissue reconstruction and integration to implant after bone-tumor resection: a current concept review. *Curr Oncol* 2024; 31(11):7190–203. doi: 10.3390/curroncol31110531
5. Lambert C, Creff G, Mazoue V, et al. Risk factors associated with early and late free flap complications in head and neck osseous reconstruction. *Eur Arch Otorhinolaryngol* 2023; 280(2):811–7.
6. Topham NS. Reconstruction for lower extremity limb salvage in soft tissue carcinoma. *Curr Treat Options Oncol* 2003; 4(6):465–75.
7. Janik S, Hirtler L, Traxler H, et al. The vascularized fascia lata free flap: an anatomical study and clinical considerations. *Eur Arch Otorhinolaryngol* 2020; 277(6):1733–9. doi: 10.1007/s00405-020-05861-8
8. Ricciardi BF, Henderson PW, McLawhorn AS, et al. Gluteus maximus advancement flap procedure for reconstruction of posterior soft tissue deficiency in revision total hip arthroplasty. *Orthopedics* 2017; 40(3):e495–500.
9. Shah AA, Lozano-Calderon SA, Berner EA, et al. Pedicled vastus lateralis myocutaneous flap for sacropelvic defects after wide oncologic resection: Wound complications and outcomes. *J Surg Oncol* 2022; 126(6):978–85.
10. Radwan RW, Tang AM, Harries RL, et al. Vertical rectus abdominis flap (VRAM) for perineal reconstruction following pelvic surgery: A systematic review. *J Plast Reconstr Aesthet Surg* 2021; 74(3):523–9. doi: 10.1016/j.bjps.2020.10.100
11. Bibbo C. The gastrocnemius flap for lower extremity reconstruction. *Clin Podiatr Med Surg* 2020; 37(4):609–19. doi: 10.1016/j.cpm.2020.07.002
12. Ha Y, Lee BH, Park JA, et al. Reconstruction of soft tissue defect around knee with thoracodorsal artery perforator flap and muscle-sparing latissimus dorsi flap. *Microsurgery* 2023; 43(7):665–75.
13. Parikh RP, Sacks JM. Lower extremity reconstruction after soft tissue sarcoma resection. *Clin Plast Surg* 2021; 48(2):307–19.
14. Delgado Perez JA, Rodriguez P, Liette MD, et al. Medial hemisoleus flap for middle third of the tibia defects. *Clin Podiatr Med Surg* 2020; 37(4):621–30.
15. Galarza L, Talbot HG, Bryant GG, et al. Locoregional flap reconstruction of the distal third of the leg – what role does it have in a modern reconstructive algorithm? *Annals Plast Surg* 2024; 92(6S):S376–8.
16. Bhagat N, Berns J, Newsom K, et al. Revisiting bipedicle flaps for lower extremity distal third defects. *Ann Plast Surg* 2023; 90:598–602.
17. Nguyen TN, Trong Mai T, Cao T, et al. Lateral supramalleolar flap for soft-tissue coverage of ankle and foot defects. *Plast Surg Hand Surg* 2023; 57(1-6):459–65.
18. Masquelet AC, Romana MC, Wolf G. Skin island flaps supplied by the vascular axis of the sensitive superficial nerves: Anatomic study and clinical experience in the leg. *Plast Reconstr Surg* 1992; 89(6):1115–21.
19. Mallett KE, Houdek MT, Honig RL, et al. Comparison of flap reconstruction for soft tissue sarcomas of the foot and ankle. *J Surg Oncol* 2021; 124(7):995–1001.
20. Tuluy Y, Ünsal MÖ, Bali ZU, et al. Reconstruction of plantar foot defects with free super-thin anterolateral thigh flap. *ANZ J Surg* 2024; 94(3):461–6.
21. Yulian ED, Qonita H, Kodrat E, et al. Limb-sparing surgery with latissimus dorsi flap reconstruction in extremity soft tissue sarcoma: Case series. *Int J Surg Case Rep* 2022; 96:107345.
22. Arguello AM, Sullivan MH, Mills GL, et al. Pedicled functional latissimus flaps for reconstruction of the upper extremity following resection of soft-tissue sarcomas. *Curr Oncol* 2023; 30(3):3138–48.
23. Lucatelli E, Lusetti IL, Cipriani F, et al. Reconstruction of upper limb soft-tissue defects after sarcoma resection with free flaps: A systematic review. *J Plast Reconstr Aesthet Surg* 2021; 74(4):755–67.
24. Sakamoto A, Noguchi T, Matsuda S. Combined latissimus dorsi and scapular flaps for reconstruction of a large defect after a shoulder sarcoma resection. *J Surg Case Rep* 2023; (3):rjad121.
25. Pinto V, Zeneli F, Di Summa PG, et al. Microsurgical reconstruction with and without microvascular anastomosis of oncological defects of the upper limb. *Healthcare (Basel)* 2024; 12(20):2043.
26. Clancy R, Lim Z, Ravinsky RA, et al. Use of a fascia lata autograft to reconstruct a large triceps tendon defect after en-bloc resection of a soft-tissue sarcoma: a case report. *JBJS Case Connect* 2020; 10(1):e0390.
27. Cha HG, Kang MK, Kim W, et al. Oncologic safety of propeller flap and free flap in reconstruction after soft tissue sarcoma resection. *J Surg Oncol* 2020; 122(4):787–94.
28. Panse N, Karanjkar A. Propeller flaps. *Indian J Plast Surg* 2022; 55(4):321–30. doi: 10.1055/s-0041-1740529
29. Fulchignoni C, Cianni L, Matrangelo MR, et al. A two-step approach to the surgical treatment of soft-tissue sarcomas. *Curr Oncol* 2024; 31:2805–16.
30. Dobke M, Mackert GA. Upper extremity sarcoma: impact of current practice guidelines and controversies on reconstructive approaches. *SICOT J* 2017; 3:15.
31. Wu SA, De Vries JA, Plantz MA, et al. Immediate plastic surgery intervention after soft tissue sarcoma resection: examining wound healing, readmission, and reoperation. *Plast Reconstr Surg Glob Open* 2023; 11(6):e4988.
32. Zhou S, Azzi AJ, Safran T, et al. A comparison of delayed versus immediate reconstruction following lower-extremity sarcoma resection. *Arch Plast Surg* 2020; 47(1):49–53.
33. Lawrenz JM, Mesko NW, Marshall DC, et al. Immediate versus staged soft tissue reconstruction after soft tissue sarcoma resection has similar wound and oncologic outcomes. *Ann Plast Surg* 2020; 85(2):163–70.
34. Haldeman PB, Harfouche C, Rosales R, et al. Immediate and delayed flap reconstruction have equivalent outcomes and associated costs following soft tissue sarcoma surgery. *J Surg Oncol* 2024; 130(3):562–68.
35. El Ezzo O, Oliva MS, Cauteruccio M, et al. Innovations in prevention of infections in oncological megaprotheses: a narrative review. *J Biol Regul Homeost Agents* 2020; 34(4 Suppl. 3):275–8.
36. Hurley AR, Zoccali G, Tasoulis MK, et al. Preoperative volume estimation in transverse upper gracilis flap surgery: a pilot study. *J Plast Reconstr Aesthet Surg* 2021; 74(11):2891–2898. doi: 10.1016/j.bjps.2021.03.101
37. Archibald H, Stanek J, Hamlar D. Free flap donor-site complications and management. *Semin Plast Surg* 2022; 37(1):26–30. doi: 10.1055/s-0042-1759795

38. Moon BM, Pae WS. Compartment syndrome as a donor-site complication of anterolateral thigh free flap: a case report. *Arch Hand Microsurg* 2022; 27(1):83–7. doi: 10.12790/ahm.21.0095
39. Tan CH, Wu Y, Satkunanatham M. Flaps for lower limb diabetic wound reconstruction: A systematic review and meta-analysis. *J Plast Reconstr Aesthet Surg* 2023; 79:74–86. doi: 10.1016/j.bjps.2023.01.032
40. Özkan B, Eyüboğlu AA, Terzi A, et al. The effect of adipose derived stromal vascular fraction on flap viability in experimental diabetes mellitus and chronic renal disease. *J Investigative Surg* 2022; 35(7):1492–501. doi: 10.1080/08941939.2022.2066741