Soft Tissue Reconstruction and Flap Coverage for Revision Total Knee Arthroplasty

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Abstract

Background: Total knee arthroplasty is a successful operation for treatment of arthritis. However, devastating wound complications and infections can compromise the knee joint, particularly in revision situations.

Methods: Soft tissue loss associated with poor wound healing and multiple operations can necessitate the need for reconstruction for wound closure and protection of the prosthesis.

Results: Coverage options range from simple closure methods to complex reconstruction, including delayed primary closure, healing by secondary intention, vacuum-assisted closure, skin grafting, local flap coverage, and distant microsurgical tissue transfer.

Conclusion: Understanding the advantages and pitfalls of each reconstructive option helps to guide treatment and avoid repeated operations and potentially devastating consequences such as knee arthrodesis or amputation.

Keywords: total knee arthroplasty, revision arthroplasty, flap, gastrocnemius reconstruction

Total knee arthroplasty (TKA) is a recognized procedure for the management of disabling knee arthritis with successful outcomes resulting in marked pain relief and improved patient functionality. Studies have cited survivorship of TKA of over 90%, 80%, and 70% at 10, 15, and 20 years, respectively [1,2]. Complications after TKA include persistent pain, stiffness, instability, or infection and can necessitate a need for revision surgery [3]. In a large meta-analysis of 9879 TKA patients followed for an average of 4.1 years, 89.3% achieved a good or excellent result, 10.7% were fair or poor, and 3.8% underwent revision [4]. Other authors have reported the incidence of deep infection associated with TKA to range from 1.0%–12.4%, all requiring revision [5,6]. With an increasing elderly population, the number of primary TKAs is projected to increase 673% by 2030, and revision total arthroplasty will likely mirror this trend, especially as patients continue to live longer [7].

Revision TKA for instability, stiffness, or persistent pain can often be accomplished in a single stage [8]. In the setting of periprosthetic joint infection (PJI), however, 2-stage reimplantation is widely accepted to be the standard of care in the United States [3,4,6,7]. The first stage involves the removal of all prosthetic material and foreign material from the joint, followed by extensive debridement, irrigation, and reaming of the medullary canals [5]. The joint is then loaded with a static or articulating antibiotic cement spacer followed by closure of the soft tissues. Provided a reaspiration of the joint is negative for persistent infection and there are no additional complications, return to the operating room is usually planned within 6–12 weeks for reimplantation [5].

Wound complications after revision TKA can present a significant problem for the surgeon and the patient including delay of reimplantation due to persistent infection, additional surgery for debridement of skin necrosis and/or flap coverage, and a longer than expected recovery period. A retrospective study at the Mayo Clinic from 1981 to 2004 found that of the 17,000 primary TKAs, there was a 0.33% incidence of wound problems requiring surgery within 30 days of index surgery [9]. Despite a low incidence, the probability of further major surgery (removal of implants, muscle flap rotation, and leg amputation) or diagnosis of deep infection in these patients was 5.3% and 6.0%, respectively, within 2 years of index surgery. In contrast, TKAs at 2 years with no postoperative wound complications had a 0.6% and 0.8% incidence of needing a major operation or a diagnosis of a deep infection, respectively. Additional patient factors to consider include patient advanced age, comorbidities, and socioeconomic status.

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diabetes mellitus, connective tissue disease, malnutrition, rheumatoid arthritis, vascular insufficiency, smoking, and steroid use, which can further delay wound healing [10-13]. Ultimately, measures that can be taken to minimize wound complications would translate into improved patient outcomes and prevent potential loss of the prosthesis or even of the limb [14].

Wound complications and multiple reoperations may compromise the soft tissue coverage of the knee, requiring treatment to fill dead space, protect the prosthesis, and close the wound. Skin or muscle flap coverage is often required in these situations, either as prophylactic treatment for anticipated wound complications or during revision. Markovich et al described 12 patients who were treated with muscle flaps used for different treatment purposes: (1) prophylactic soft tissue coverage before definitive reconstruction, (2) muscle flaps for treating infected prostheses with deficient soft tissue coverage, and (3) salvage muscle flaps for wound dehiscence or necrosis in the immediate postoperative period. At an average 4.1-year follow-up, the wound was revascularized in 100% of knee, and the prosthesis preserved in 83% [11].

Although complex wound coverage is often driven by the plastic surgeon, the orthopedic surgeon should be familiar with the reconstructive options and actively participate in decision making to facilitate a collaborative effort toward the best possible patient outcomes. In this review, the management of wound complications and soft tissue defects surrounding the knee will be discussed, with specific focus on skin grafts, local skin flaps, and free flap coverage.

**Vascular Considerations**

An extensive knowledge of knee vascular anatomy is essential to guide both the orthopedic approach to revision TKA to prevent devascularization of skin or bone and when helping the plastic surgeon in reconstructive planning (Fig. 1).

The main blood supply to the knee arises from branches from the femoral artery, popliteal artery, and anterior tibial artery. The skin surrounding the knee is perfused through an anastomosis of vessels just superficial to the deep fascia, fed by underlying perforating vessels [14]. Perforators over the medial and anterior aspect of the knee are supplied by the saphenous branch of the descending genicular artery, with a small contribution anterior inferiorly from the anterior tibial recurrent artery. Perforators feeding the deep fascial plexus laterally include the superior and inferior lateral genicular branches of the popliteal artery [15]. The deep fascial vascular network sends vessels that penetrate the subcutaneous fat to reach the epidermis; however, there is little communication between vessels at the superficial level. Therefore, wide dissection superficial to the deep fascia will compromise the blood supply to the skin, whereas dissection deep to the fascia will maintain the skin blood supply [16]. This illustrates the need for elevation of full-thickness skin flaps during dissection.

The blood supply to the patella should be preserved to prevent patellar osteonecrosis and fragmentation, both of which can lead to periprosthetic and wound infections [16]. The patellar blood supply arises from an anastomotic ring fed by the muscular–articular branch of the descending geniculate artery, the 4 genicular arteries (superior medial, inferior medial, superior lateral, and inferior lateral), and the anterior tibial recurrent artery, from which the transverse infrapatellar artery and the oblique prepatellar arteries arise. Importantly, this vascular network does not contribute significantly to skin blood supply because of lack of communication through the prepatellar bursa. Intraosseous blood supply to the patella arises from penetrating vessels from the inferior aspect of the patella and from the middle third of the anterior surface of the patella [17].
During initial arthroplasty using a standard parapatellar approach just medial to midline, contribution of the 3 medial blood vessels (saphenous, superior medial genicular, and inferior medial genicular) supplying the patella will be interrupted. In addition, the inferior lateral genicular artery will be interrupted during excision of the lateral meniscus, and branches of the anterior tibial artery may be removed during excision of the fat pad [16,18]. If not already divided, care should be taken during revision to preserve the superior lateral genicular artery, which can be found deep to the synovium in the plane of the vastus lateralis muscle [15].

During revision TKA, the posterior cruciate ligament is commonly removed or no longer functioning [16]. Care should be taken when removing the posterior cruciate ligament as it is possible to penetrate the posterior capsule and damage the popliteal contents, including the popliteal artery and vein, and tibial nerve. Branches of the popliteal artery may also be damaged including genicular arteries that could compromise skin and patellar blood flow and sural arteries, which may impair blood supply to the gastrocnemius muscle, compromising an important option for reconstruction.

Approach to Wound Closure

Closure during revision TKA can present a challenging problem to the orthopedic surgeon. Adequate soft tissue coverage is essential to lower the rate of infection and careful consideration must be given for the potential for reoperation, especially in the setting of 2-stage reimplantation. Before closure, adequate debridement of nonviable tissue is of utmost importance. Selection of the appropriate method of closure and coverage needed should be based on careful assessment of the wound and associated risks, treatment morbidity, reoperation, recovery time, and long-term prognosis. The reconstructive ladder may be used as a general guide to stratify reconstructive options. The simplest method of closure is denoted on the bottom rung, with progressive rungs representing sequentially more complex reconstructive techniques (Fig. 2) [19]. If success rates of lower rung options are thought to be low, the concept of a reconstructive “elevator” allows the surgeon to jump directly to the level of reconstructive complexity with a highest chance for success. It is essential that the operation with the highest probability of success be the first choice in the “reconstructive ladder” of procedures.

Prophylactic measures can also be taken in cases of anticipated wound closure problems. Casey et al retrospectively reviewed 23 patients who underwent prophylactic flap coverage before TKA for high risk of wound complications, mainly because of prior operations and infections around the knee. They found that despite a high rate of complications at the time of flap transfer, up to 48%, all patients successfully underwent subsequent TKA with no wound complications. Conversely, they reviewed 18 patients who had a salvage procedure done with flap coverage after TKA implantation and found that complications were similarly high; however, 3 patients required above-the-knee amputation. In both prophylactic and salvage procedures, both the orthopedic and plastic surgeon together should decide what treatment option has the best chance for success based on individual patients risk and history.

In cases of salvage reconstructive procedures, careful preoperative planning must be done, taking into account patient’s previous surgical history, prior surgical incisions, and chance for further wound complications. Menderes et al reviewed the results of 17 patients with complex wounds after TKA and the impact of patient-specific factors, wound factors, choice of operation, and secondary procedures on clinical outcomes. They reported 94% prosthesis retention, with 30% reoperation rate. Menderes et al recommended using a fasciocutaneous flap when the defect was small or if bone or tendons were exposed, and a musculocutaneous flap for covering large defects, especially if the prosthesis is exposed [20].

Primary and Secondary Closure

Primary closure is the preferred method of closure after revision TKA; however, it should not be done in the setting of high wound tension or devascularized skin flaps due to scarring from prior surgeries. Delayed primary closure is not indicated in the setting of PJI or exposed prosthesis. However, in the setting of excessive skin tension without infection, delayed closure could be considered to prevent more invasive reconstruction. Delayed closure takes advantage of the viscoelastic creep inherent in the skin, giving time for the skin to close small defects [21]. Such methods include use of vessel loop shoelace method, although this method requires return visits to the operating room for tightening, progressive manual tensioning of sutures at the bedside, or daily reapplication of tensioned SteriStrip [21,22].

Healing by secondary intention is not recommended in the case of arthroplasty with exposure of nonvascularized structures such as bone, hardware, and tendons [21]. As an alternative to secondary closure, a vacuum-assisted closure (VAC) device may be applied to an open wound bed and can be used as a temporizing measure to delay definitive closure or to assist in closure of small full thickness and partial thickness soft tissue defects, as long as there is no exposed bone or prosthetic material. Argenta et al [23] first developed the VAC in the 1990s as a novel method for closure of large, chronic wounds that could not be closed by another measure. Through use of negative-pressure dressings, the VAC facilitates movement of distensible soft tissue toward the center of the wound and aids in the evacuation of interstitial fluids that may accumulate [24]. These interstitial fluids are also thought to contain inhibitory factors that suppress the formation of fibrous tissue which are
crucial to wound healing [24-27]. When placing the VAC, it is important to debride nonviable bone and soft tissue. In addition, although a VAC sponge may be placed over exposed hardware, it is recommended to limit exposure to the sponge to less than 72 hours, making it less useful in 2-stage revision arthroplasty [21]. The VAC is often set to a pressure of 100-125 mm Hg continuous suction [28]. Complications, although rare, include bleeding from the wound, pain with changing of sponges, and excessive growth of granulation tissue into the sponge [21].

Skin Grafts

Skin grafts can be used in cases of skin loss due to necrosis or in combination with flap harvest for coverage of the recipient site in the setting of flaps lacking a cutaneous component. In addition, limited soft tissue coverage over the anteromedial aspect of the proximal tibia often requires skin grafting at the time of revision surgery to prevent wound problems [29,30]. Skin grafts can be harvested as both split-thickness and full-thickness skin grafts [31]. Skin grafts heal by way of oxygen diffusion from surrounding tissues (plasmadic imbibition) and lining up of graft and recipient blood vessels (inosculation) for the first 2-3 days followed by new vessel in-growth by angiogenesis. As such, viable subcutaneous tissue, muscle, fascia, periosteum, or paratenon is required at the recipient site for graft survival [21]. Skin grafts should not be placed on an infected wound bed.

Full-thickness skin grafts include the entire thickness of the epidermis and dermis (>0.6-mm thick) and require primary closure of the donor site [32]. Split-thickness grafts include the epidermis and an only small portion of the dermis (between 0.15 and 0.6-mm thick) and do not require donor site closure due to re-epithelialization from the peripheral epidermal basal layer and underlying deep dermal adnexal structures [32]. Although full-thickness skin grafts tend to have less secondary contracture than split-thickness skin grafts, they are often not used in the lower extremity because of donor site availability and an increased risk of complete or partial loss. The thicker graft has an increased diffusion distance required in the early healing phases, making it more sensitive to shear forces, underlying fluid collection, excessive electrocoagulation of the wound base, and vasocostrictive effects of smoking [31]. Split-thickness skin grafts are more prone to contracture and scarring, which is an important aspect when considering range of motion across a joint. The thinner split-thickness skin grafts, however, offer the advantage of large donor site availability and improved graft take on wound beds with poor vascular supply. In addition, split-thickness skin grafts can be meshed to increase surface area, improve take over irregular wound bed contours, and prevention of graft failure from underlying hematoma and/or seroma formation.

After harvest of a skin graft, the graft should be secured at the recipient site to promote incorporation. This can be done with negative-pressure dressings, VAC use, or application of a bolster [21,33]. Vacuum pumps should be used with continuous suction, which minimizes shearing. For management of the donor site, potential dressings include use of occlusive cellophane on small sites, silver-impregnated gauze, or topical silver [21,34,35].

Principles of Flaps

Tissue flaps differ from skin grafts in that they are transferred to a wound bed with an intact blood supply, allowing for more robust coverage of larger defects with higher bacterial counts and wounds with exposed hardware, exposed bone or tendon, and vital structures such as blood vessels and nerves. Tissue flaps can be classified according to location (local, regional, or distant), type of tissue (fasciocutaneous, muscle, musculocutaneous), blood supply (random, axial), and method of transfer (pedicled, free flaps) [21]. For the knee, the location of the flap taken for transfer can be local or regional from the gastrocnemius, tibialis anterior, or vastus lateralis, or taken as distant or free from sources such as the latissimus dorsi, rectus abdominis, gracilis, serratus anterior, or the anterolateral thigh (ALT).

Flap blood supply can be random, based on the subdermal plexus, or axial, which is based on an inflow vessel or pedicle. In the lower extremity, the length-to-width ratio recommended when using random pattern flaps is 2:1, where axial flaps allow for greater freedom in the length-to-width ratio and flap transposition. The method of transfer is of significant importance in determining surgical options [36]. Local and regional axial pattern flaps are based on preservation of an intact pedicle, which is used as the axis to transfer tissue by way of transposition, rotation, or advancement [37]. Regional flaps may also be taken in an island fashion where the flap is only attached by the pedicle allowing for greater mobility of flap placement.

Muscle flaps are most commonly used in reconstruction around the knee; however, they require a skin graft on the transposed muscle to complete closure of the defect. Muscle flaps can be classified according the Mathes and Nahai classification based on their blood supply or pedicle: type I (single dominant vascular pedicle), type II (1 dominant and 1 minor pedicle), type III (2 dominant pedicles), type IV (segmental branches), and type V (1 dominant and multiple minor pedicles; Table 1) [38,39].

Free flaps (also known as microsurgical flaps) refer to the transfer of tissue with its vascular pedicle from a distant site to a recipient site, where the pedicle is anastomosed to local vessels with microsurgery. Although more technically demanding, they can provide greater surface area coverage, can be tailored fitted to a defect, and can rely on blood supply outside of the operative zone. Studies indicate that free flaps may have a greater antibiotic capacity and ability to deliver humoral defense factors, potentially reducing the risk of postoperative infection [14,40]. Disadvantages of free flaps include donor site morbidity, longer operative time, and delayed rehabilitation of the knee [14,41].

During preoperative planning, the orthopedic and plastic surgeons should consider the type and volume of tissue deficiency, size of wound surface area, risk of infection, and need for future reoperation to help guide selection of flap coverage. Local and random based flaps are typically not used in coverage of wounds around the knee because of poor local skin mobility, excessive scar tissue from multiple operations, and unreliable subdermal blood supply. Therefore, this review is focused on regional and free flap options.

Surgical Technique and Progressive Options

Pedicle Flaps

Pedicle flaps should be considered when regional options are available and wound size permits. Typically, a pedicle flap is used

<table>
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<th>Table 1</th>
<th>Mathes and Nahai Classification of Reconstructive Flap Coverage.</th>
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<td>Type</td>
<td>Example Flap</td>
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<tr>
<td>Type I: single dominant vascular pedicle</td>
<td>Tensor fascia lata</td>
</tr>
<tr>
<td>Type II: 1 dominant and 1 minor pedicle</td>
<td>Gracilis</td>
</tr>
<tr>
<td>Type III: 2 dominant pedicles</td>
<td>Gluteus maximus</td>
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<td>Type IV: segmental branches</td>
<td>Sartorius</td>
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<td>Type V: 1 dominant and multiple minor pedicles</td>
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for first option reconstruction as they do not prevent later free flap use if necessary. Careful attention to prior surgeries may uncover compromise to axial inflow to these flaps in which they should not be used in this setting.

Gastrocnemius

The gastrocnemius flap is the regional workhorse for reconstruction of the upper third of the leg and defects of the knee (Fig. 3). Its use for coverage of exposed knee prosthesis was first described by Barford and Pers in 1970 to aid in primary closure of compound injuries of the knee and further described by Sanders et al in 1981 [42,43]. Gastrocnemius flaps can provide excellent results during revision TKA for select patients. Preoperative planning for potential gastrocnemius flap must take into account the variable size of the muscle relative to the defect [38].

Anatomy

The gastrocnemius muscle consists of medial and lateral heads, which originate from their respective femoral condyles and join just distal to the knee and are innervated by the tibial nerve. The muscle becomes tendinous near the junction of the middle and distal thirds of the leg where it joins the soleus tendon to form the Achilles tendon. Each muscular head is supplied by a medial and lateral sural artery branching directly off of the popliteal artery, making it a Mathes and Nahai class I circulation pattern. The sural artery enters the muscle just beneath the level of the joint space and arborizes proximal in the muscle [38]. This artery serves as the pedicle about which either head is rotated for coverage of the medial or lateral knee. The medial head is preferred for reconstruction as it is larger and longer (3.0–4.0 cm) than the lateral head and has a longer vascular pedicle allowing for greater arc of rotation to reach the knee [14,38]. In addition, the common peroneal nerve crosses posterior to the lateral head of the gastrocnemius and may be injured intraoperatively when the lateral gastrocnemius is used.

Medial Gastrocnemius Flap Elevation

To reach the medial head of the gastrocnemius, a longitudinal incision can be made either posterior midline or parallel to the medial border of the tibia, extending from the tibial plateau to 8–10 cm above the ankle. The saphenous vein is preserved and the muscle is separated from the overlying subcutaneous tissue. The plane between the soleus and medial portion of the gastrocnemius is developed by blunt finger dissection down to its attachment at the joint Achilles tendon. The medial portion of the gastrocnemius contribution to the Achilles tendon is divided 1 cm distal to the musculoperoneofibular junction to allow for easy suture tacking to the recipient site. The median raphe separating the medial and lateral heads can then be identified. Care is taken to preserve the sural nerve and lesser saphenous vein by gently retracting them laterally before dividing the raphe. Care should be taken not to damage the sural vessels when approaching the knee joint. If the medial head does not reach the wound, the muscular fascia can be scored or the muscle can be released from its origin on the medial femoral condyle adding 5–8 cm of rotation [38,44,45] (Fig. 4). The flap is then grafted with a meshed split-thickness skin graft.

Lateral Gastrocnemius Flap Elevation

To mobilize the lateral head of the gastrocnemius, a longitudinal incision is made either posterior midline 2–3 cm posterior to the fibula. The common peroneal nerve should be identified and preserved at the neck of the fibula. The lateral head is separated from the medial head as previously described, and the muscle is then transposed into position and skin-grafted [38].

Results

The gastrocnemius flap is the most common muscle flap used for reconstruction after TKA. Nahabedian et al [11] reported an 84% prosthesis salvage rate using medial gastrocnemius transposition in 29 wound problems after TKA. Corten et al [46] reported on 24 patients treated with gastrocnemius muscle flap coverage during the first stage of 2-stage reimplantation for infected TKA and found that 22 patients (92%) obtained a satisfactory result, with Knee Society Score improvement from 53 preoperatively to 103 at 4.5-year follow-up.

The gastrocnemius muscle may be less effective for treatment of more proximal defects, up to the level of the superior pole of the patella, because of the length of the vascular pedicle and the muscle itself. Ries et al reported on 12 patients who underwent medial gastrocnemius transposition flap after TKA. They found that for patients with defects over the tibial tubercle or patellar tendon, the flap healed and salvaged the TKA. However, if the defect extended proximally to the patella or quadriceps tendon, 3 of 4 patients required additional coverage with fasciocutaneous, lateral gastrocnemius, or free flap coverage and 1 patient required an above-knee amputation [47]. Overall, the gastrocnemius flap can help fill large soft tissue defects around the knee and has a high rate of success of salvaging the prosthesis and limb.
**Vastus Lateralis**

Failure of the gastrocnemius flap can present as a challenging situation; however, the distally based vastus lateralis may be a potential local solution for select patients. The vastus lateralis is less commonly used as it can be more challenging to use to fill medial defects.

**Anatomy**

The vastus lateralis is the largest of the quadriceps femoris muscles and originates as a broad aponeurosis from the upper part of the intertrochanteric line and anterior and inferior borders of the greater trochanter. The muscle inserts via a thickened flat tendon into the lateral border of the patella, blending with 3 other tendons to form the quadriceps tendon. The vastus lateralis demonstrates a Mathes and Nahai class circulation pattern and receives its dominant blood supply from the descending branch of the lateral femoral circumflex artery and a distal minor pedicle from the superior lateral geniculate artery. It receives its nervous supply from the femoral nerve. The superior lateral geniculate artery gives rise to 3 branches that enter the muscle belly distal and posteriorly in which at least 2 are needed to vascularize the vastus lateralis after ligation of its dominant blood supply [48,49].

**Surgical Technique and Results**

The patient is positioned supine or in the lateral decubitus position and a longitudinal incision is made along the lateral aspect of the thigh from the greater trochanter (10 cm below the anterior superior iliac spine) to the lateral patellar border. After dissection to the deep fascia, the anterior and posterior borders of the vastus lateralis are identified. The rectus femoris is then retracted medially to identify the descending lateral femoral circumflex artery, which passes under the rectus femoris and enters the vastus lateralis around the level of the greater trochanter. This pedicle can be divided; however, a segment should be preserved in case the flap needs to be supercharged if the minor pedicles are inadequate for flap perfusion. The origin of the muscle is then incised and the muscle is separated from the biceps femoris and vastus intermedius until 5 cm proximal to the lateral femoral condyle. Transposition of the flap is now possible [50]. This flap may also be harvested in a delayed fashion where the main pedicle is cut in small operation and then the flap is harvested 1-2 weeks later.

The vastus lateralis is not commonly used and often follows failure of a gastrocnemius flap, and there are limited reported cases on its use. Auregan et al reported on 4 patients, 3 of which were used around revision TKA. In all cases, skin closure was achieved; however, final joint mobility was poor at 45° on average [50]. It is important to note that the use of this flap will eliminate the possibility of downstream use of an ALT free flap due to ligation of the descending branch of the lateral femoral circumflex.

**Free Flaps**

Free flaps represent the highest rung on the reconstructive ladder and may only be necessary in patients with persistent infection after prior failed reconstruction with regional options. As such, free flaps should only be considered for defects that cannot be covered by a pedicled flap. Benefits of free flaps include the possibility for reoperation such as in a 2-stage implantation, prevention of postoperative knee stiffness, and a robust blood supply to allow for less complications in patients at high-risk for skin necrosis and wound dehiscence [51]. Disadvantages include donor site morbidity, high technical acumen, and a longer operative and recovery time.

In contrast to a pedicled flap, survival of a free flap depends on early maintained patency of a microsurgical Anastomosis between the flap vascular pedicle and a recipient artery and vein [52]. The first 24-48 hours after surgery is the period with the highest chance of vessel thrombosis and requires frequent clinical and external Doppler monitoring by an experienced team trained in recognizing vascular compromise. After 5 days, the anastomosis endothelializes and risk of thrombosis decreased substantially. Surgical technique and inexperience are the most common causes of thrombosis, with factors such as inclusion of adventitial tissue, trauma to the intima, or exposure to subintimal structures increasing the chances of microsurgical failure [52]. Free flaps can be harvested as pure muscle flaps with recipient site skin grafting, musculocutaneous flaps, or fasciocutaneous flaps. Muscle flaps with skin grafting, however, are the best option for the complicated wound.

Recipient vessels for free flap transfer should be carefully selected to ensure success of the free flap transfer. Although there is no clear consensus, the branches of the popliteal artery are most commonly used. However, the popliteal artery itself has limited utility in free flap transfer to the anterior surface of the knee [53]. The popliteal artery divides into the anterior and posterior tibial arteries, which are better able to support flap transfer. The superficial femoral artery and genicular arteries can also be used, and an individual decision must be made based on the patient’s anatomy [53].

**Latissimus Dorsi**

The latissimus dorsi is a commonly used free flap for a variety of lower extremity reconstructive purposes and may be taken as either a muscle or myocutaneous flap (Fig. 5). It has sufficient bulk to fill large volumes of dead space and can cover a large surface area; the muscle also shrinks with pressure garments, leaving a good contour at the knee [21]. The latissimus dorsi flap has a long pedicle that allows for anastomosis outside the surgical site that may have extensive scarring from prior operations. A major disadvantage of latissimus dorsi free flap is the common occurrence of donor site seroma, which can be managed with repeated aspirations or excision [37].

**Anatomy and Surgical Technique**

The latissimus dorsi muscle, innervated by the thoracodorsal nerve, has a broad origin extending from the thoracic spinous processes and posterior iliac crest and inserts into the medial side of the intertubercular groove on the posterior humerus. The latissimus dorsi has a Mathes and Nahai type V circulation classification.

![Fig. 5. Harvesting of a latissimus dorsi flap for grafting about the knee.](image)
with the primary blood supply from the thoracodorsal vessels, which serve as the pedicle for transfer and minor segmental branches from the lumbar and/or intercostal vessels.

When harvesting the latissimus dorsi flap, the patient is positioned in the lateral decubitus position. An oblique incision is made along the anterior aspect of the muscle, and the anterior leading edge of the muscle is identified. The muscle is elevated off the posterior thorax and its broad origin is divided. Care is taken when dissecting toward the axilla to protect the dominant pedicle. The insertion is then divided before dividing the pedicle. During dissection, the serratus branch of the thoracodorsal artery is identified and divided, which provides the longest vascular pedicle for the latissimus flap [54].

**Rectus Abdominis**

The rectus abdominis muscle free flap can provide coverage for large lower extremity defects, has a long and consistent vascular pedicle, and low donor site morbidity. It can be harvested as either a muscle only or a myocutaneous flap [55]. A major disadvantage of harvest is the potential for herniation unless the rectus sheath is carefully closed [37]. Contraindications include patients who have had previous abdominal or pelvic surgery that may compromise the flap vascular supply, patients with significant abdominal girth who may be at higher risk for pulmonary and abdominal wall complications, and patients with previous vascular surgery on the iliac system [56].

**Anatomy and Surgical Technique**

The rectus abdominis muscle arises from the pubic symphysis and pubic crest and inserts on the fifth, sixth, and seventh costal cartilages. There are 3-5 fibrous bands (tendinous intersections) that divide the muscle that are firmly adherent to the anterior sheath. The rectus abdominis is a Mathes and Nahai type III flap as it is supplied by the inferior and superior epigastric vessels. An oblique incision is made in the lateral decubitus position. An oblique incision is made above the arcuate line and dissected down to its iliac origin. The muscle is then detached from the posterior rectus sheath above the arcuate line, halfway between the pubis and umbilicus [54].

To harvest the muscle, a longitudinal incision is made down to the level of the anterior rectus sheath. The skin and subcutaneous tissue are elevated off the rectus muscle. An incision is made in the anterior rectus sheath, with care to create a cuff of fascia with the perforators that supply the skin if a myocutaneous flap is planned. The tendinous intersections at the linea alba and semilunaris are addressed first to free the most adherent portion of the muscle. The rectus abdominis is then dissected off the posterior rectus sheath above the arcuate line, with care taken to not injure the muscle, which runs in the undersurface of the muscle belly [54]. At the level of the arcuate line, the deep inferior epigastric vessels can be identified entering laterally and dissected down to its iliac origin. The superior epigastric is then ligated and the muscle insertion detached. The inferior epigastric is then ligated proximally to preserve pedicle length and the flap is ready for transfer. The abdominal defect must be carefully closed to prevent herniation of the anterior abdominal wall.

**Gracilis**

The gracilis free flap can be considered as an effective alternative for knee reconstruction in the case of failed gastrocnemius flaps or in addition to a medial or lateral gastrocnemius flap [57]. It can be harvested as either a muscle or myocutaneous flap. Functionally, the gracilis muscle is of lesser importance in leg adduction, and therefore, donor site morbidity is uncommon [58]. Advantages to the gracilis flap include primary direct donor site closure with inconspicuous scars and that the gracilis flap can be used as a sensory flap when a nerve supply via a branch of the obturator nerve is present [57].

**Anatomy and Surgical Technique**

The gracilis muscle, innervated by the obturator nerve, originates as a thin aponeurosis from the anterior margins of the lower half of the symphysis pubis. Its tendinous insertion passes behind the medial condyle of the femur, curving around the medial condyle of the tibia, and joins the pes anserinus. The gracilis muscle has a Mathes and Nahai type II circulation and receives its dominant blood supply from the ascending branch of the medial circumflex femoral artery with a minor pedicle from 1 to 2 branches off the superficial femoral artery.

In harvesting a gracilis, the patient is positioned supine, with the thigh abducted. A line is drawn from the pubic symphysis to the medial condyle in which the gracilis muscle is located 2-3 cm posterior. The position of the gracilis muscle is also identified by palpation in thinner patients, and the vascular pedicle may be audible on Doppler examination. The dominant pedicle is commonly 8-10 cm inferior from the pubic tubercle. When harvesting for free tissue transfer, a 10- to 15-cm sagittal incision is made from the pubis to the medial anterior knee [55,57]. The muscle is then dissected and dissected from distal to proximal, separating it from the sartorius and semimembranosus muscles. Care is taken more proximally to preserve the dominant pedicle, before more superior dissection to release the muscle origin. To expose the pedicle, the adductor longus is retracted medially and the pedicle traverses on top of adductor magnus. After superior release of the muscle, the pedicle is divided and ready for transfer.

The gracilis can also be taken as a distally based pedicled flap based on the minor pedicles from the superficial femoral artery. In this case, it is often recommended to delay the flap with an operation that ligates the dominant pedicle 2 weeks before flap transfer. After skin incision, the muscle origin is divided and dissection is carried out proximal to distal until the minor pedicle(s) are encountered in the lower third of the muscle. The muscle flap is then reversed 180° and tunneled under the skin of the anterior aspect of the distal thigh to reach the exposed wound and/or prosthesis [55].

**Results**

Cetrulo et al reported on 11 patients with complex wounds and exposed total knee prostheses with free tissue transfer, of which 3 patients had failed previous local muscular rotation flap coverage. Five patients received latissimus dorsi muscle flaps and 6 patients received rectus abdominis muscle flaps. All of the free flaps were successful (100%), the limb was salvaged in 100%, and the prosthesis salvaged in 10 patients (91%) [59]. Hierner et al reported on the use of prophylactic latissimus dorsi free flap coverage with TKA. Fourteen patients were reviewed who had on average 10 previous surgeries and for whom gastrocnemius free flap was not an option. They found that primary wound healing occurred in 8 patients, skin breakdown occurred in 5 patients requiring secondary skin grafting, and 3 late recurrences of infection occurred. Overall, free latissimus dorsi transfer made prosthesis implantation possible, prevented postoperative knee stiffness, and had a low rate of severe complications in patients at high risk for wound-healing problems [51].

**Anterolateral Thigh**

The ALT flap is a free fasciocutaneous flap (no muscle) and is most commonly used in patients with large, superficial skin loss >4 cm, without joint or implant exposure and without deep infection [10,14]. Recent head-to-head studies comparing muscle
to fasciocutaneous flaps are finding that infection is likely not a contraindication for the use of fasciocutaneous flaps, however, muscle flaps tend to have a more robust blood supply [40]. The main advantages are improved cosmetic outcomes, better pliability, and easier revision, no need for skin grafting, and no donor site weakness [37]. However, there are limited studies regarding its use in periprosthetic infection [14]. Disadvantages include a more technical flap harvest and poor vascularity in the setting of the obese patient with a thick layer of subcutaneous fat on the lateral thigh.

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The blood supply to the ALT flap is the descending branch of the lateral femoral circumflex artery (LFCA), which traverses in the intermuscular septum between the rectus femoris and vastus lateralis [60]. Perforating vessels supplying the skin may course through the vastus lateralis muscle (type C: musculocutaneous) or pass directly between the muscles on the septum (type B: septocutaneous). Kuo et al reported on the success and anatomic variability of 140 ALT flaps transferred for reconstruction of various soft tissue defects. They found that the blood supply to the skin came from the septocutaneous perforators only in 19 patients (13.6%), from the descending or transverse branch of the LFCA or directly from the LFCA. Other variations included supply by musculocutaneous perforators that were elevated as a true perforator flap via intramuscular dissection (n = 34; 24.3%) or used a cuff of vastus lateralis for added bulk (n = 87, 62.1%) [44]. About one third of the population has an extra vessel in the ALT in the plane between the rectus femoris and vastus lateralis, known as the oblique branch of the lateral circumflex femoral artery, which can also be reliably used as the pedicle of the ALT flap [61,62].

For harvest, a line is first drawn from the anterior superior iliac spine to the superlateral border of the patella, which represents the muscular septum between the rectus femoris and vastus lateralis muscles. Cutaneous perforating vessels can then be identified using a handheld Doppler centered over the midpoint of this line, and skin markings can be made to include these vessels. A skin flap can be designed in the middle third of this line, extending approximately 10 cm below the anterior superior iliac spine to 7 cm superior to the lateral patella. An incision is made at the medial border of the flap over the rectus femoris, through the deep fascia, so that the flap is raised laterally until the intermuscular septum is reached. The pedicle is then identified in the groove between the rectus femoris and vastus lateralis muscles. If the perforators are through the vastus lateralis, a 2-cm cuff of muscle is harvested with the flap to protect the vessels. The pedicle is then carefully dissected proximally to achieve a length of 12 cm. The lateral skin incision is made and the flap elevated [54].

**Results**

The ALT flap can be used in select patients for reconstruction of the knee. In a larger series, Kuo et al [63] reported on the success rate at time of operation was 92%, and at 2-year follow-up, all flaps had healed uneventfully with minimal morbidity. Lewis et al reported on 7 patients with exposed total knee prostheses that were treated with a fasciocutaneous flap. One patient required concomitant reconstruction with a medial gastrocnemius flap and one patient experienced mild wound separation secondary to a severe spasm; however, no other complications occurred in 1-year follow-up [64]. Townley et al prospectively followed 100 patients with ALT flaps taken for various reconstructive procedures and followed them for 6 months for donor site complications. They found that tingling was the more common symptom (59%), whereas pain, itching, muscle herniation, and quadriceps muscle weakness were infrequent [65].

**Postoperative Considerations**

Patients after flap and graft reconstruction need graduated mobilization and weight bearing after their operation. Initially for about 7 days bed rest is needed for optimal healing of the flap and/or graft. During the next 2 weeks, progressively increasing mobilization and weight bearing is followed. For about 4-6 months postoperatively, patients should use compression stockings to provide support to the skin graft to prevent breakdown.

During the postoperative period, because of prolonged immobilization, patients should be on a standard protocol of subcutaneous heparin or enoxaparin.

**Complications**

Vascular compromise is the most serious and potentially devastating complication of flaps, especially in the setting of free tissue transfer (Table 2). Prompt surgical intervention is needed in these situations to restore blood flow and attempt to salvage the flap. Venous compromise causing congestion is more common, as the venous side of the flap is a low-flow system. Failure to re-establish effective perfusion within 2 hours usually results in irreversible insult to the muscle flap [37]. After microsurgical anastomosis in free flaps, a multitude of different monitoring devices and techniques have been used to aid in assessing free flap viability. Clinical examination remains the gold standard method of flap assessment, and external Doppler examination is useful when a perforator or intramuscular vessel can be audibly identified. In addition, use of implantable venous Doppler monitoring may shorten the time to the detection of vascular thrombosis, potentially improving free flap salvage rates. Swartz et al reviewed 103 patients with venous monitors implanted, which detected 16 of 16 thromboses, with 12 flaps salvaged. Overall, the implantable Doppler showed a higher level of detection of venous thrombosis and helped to salvage a majority of flaps [66]. Early flap hematoma may also result in vessel compression leading to flap compromise and should be addressed promptly.

Donor site complications can include hematoma, seroma, sensory nerve dysfunction, and scar formation, which can be problematic for patients and potentially necessitate reoperation. Muscle weakness is also common in the cases of muscle flaps, but this is often transient and compensation occurs quickly. Kramers-de Quervain et al objectively evaluated donor site morbidity after harvest of the gastrocnemius or soleus for flap procedures. They evaluated 5 patients using comprehensive gait analysis during free level, fast level, and uphill walking. They found no relevant donor site morbidity in free walking; in fast level walking, there was a slight decrease in the second vertical peak force during push off. During uphill walking, they found a compensatory strategy in all patients, reducing the demand on the posterior calf muscles. Patients shortened the length of the step on the contralateral side, and also exhibited a calcaneal motion pattern, meaning increased ankle dorsiflexion, showing decreased function of the posterior calf muscles [67].

**Table 2**

Pearls to Achieve Success and Prevent Complications.

<table>
<thead>
<tr>
<th>Pearls for Successful Flap Coverage About the Knee</th>
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<tbody>
<tr>
<td><strong>Adequate and thorough debridement of vascular bed in host site and donor site</strong></td>
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<tr>
<td><strong>Use of wound vac is contraindicated in the presence of a wound infection</strong></td>
</tr>
<tr>
<td><strong>Adequate and appropriate antibiotic therapy based on cultures</strong></td>
</tr>
<tr>
<td><strong>A gastrocnemius flap will work for most patients. Its presence in the middle of the reconstructive ladder recommends consideration of a gastrocnemius flap before other pedicled and free flaps.</strong></td>
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<tr>
<td><strong>The operation with the highest probability of success is the best operation</strong></td>
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Summary

Soft tissue reconstruction of the knee may be necessary with TKA in the setting of previous surgeries to the knee, insufficient soft tissue coverage, infection, or poor wound healing. With the increasing incidence of PJIs necessitating revision TKA, reconstruction has become increasingly important for adequate closure and prevention of future infection. An array of management options are available; however, thorough evaluation of the patient and extremity and careful selection of soft tissue coverage with plastic and orthopedic collaboration are required and can produce positive outcomes.

References


