Handbook of Lower Extremity Reconstruction

Clinical Case-Based Review and Flap Atlas

Scott T. Hollenbeck *Editor*

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Editor
Scott T. Hollenbeck
Plastic and Reconstructive
Surgery
Duke Medical Center
Durham, NC
USA

Associate Editors
Peter B. Arnold
Plastic and Reconstructive
Surgery
University of Mississippi
Medical Center
Jackson, MS
USA

Dennis P. Orgill
Division of Plastic Surgery
Brigham and Women's Hospital
Harvard Medical School
Boston, MA
USA

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To our families for their support and patience. To our teachers for their effort and knowledge. To our patients for their trust and resilience. To our trainees for always questioning and pushing forward. To our assistants and partners for having our back.

Scott T. Hollenbeck
Peter B. Arnold
Dennis P. Orgill

Preface

I often ask residents and students to define the goal of lower extremity reconstruction. I hear all kinds of answers from "limb salvage" to "return to work" to "bony healing." At the end of the day, I think the goal of lower extremity reconstruction can best be summarized simply as "painless ambulation." If this goal is achieved, then the reconstructive surgeon has done their patient a service.

In this book, you will find a broad range of topics designed to prepare surgeons who will encounter lower extremity wounds. As the majority of reconstructive lower extremity wounds are traumatic in nature, we focus primarily on trauma care. However, important topics such as diabetic limb salvage, nonsurgical wound care, and oncologic reconstruction are also covered. The book is divided into two parts. Section I consists of concepts and anatomic region-specific discussions. Section II is essentially an atlas for performing flaps for the lower extremity. Rather than simply showing how to dissect a given flap, the atlas is unique in that it is defect based. For example, a defect of the knee is shown, and several flap options are presented for that specific problem. In my mind, this is far more practical than a flap dissection guide.

The atlas's illustrations are meant to show the key steps in setting up and raising the flap for a given defect. We realize there are many ways to do each flap and to address each problem. What we have presented here is what we believe to be *the most practical and reliable approach*. Certainly, extreme options and sophisticated approaches exist. Many of those esoteric approaches are best for the surgeon who has achieved expert status.

We hope this book will be useful to those "on the front line" – residents seeing consults in the emergency room, students preparing for plastic surgery or orthopedics rotations, and attending surgeons embarking on a comprehensive reconstructive clinical practice. Whatever the circumstance may be, we designed this book to help readers deliver real-time care. With hard work and perseverance, achieving painless ambulation for your patients is an attainable and worthwhile goal.

Durham, NC, USA Scott T. Hollenbeck, MD
Jackson, MS, USA Peter B. Arnold, MD
Boston, MA, USA Dennis P. Orgill, MD, PhD

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The authors would like to acknowledge the pioneering work of John B. McCraw and Phillip G. Arnold. Their flap atlas has inspired many and remains a useful resource and true work of art. This book would not exist without the dedication and tireless work of our esteemed colleagues who contributed valuable time and effort to writing chapters and generating figures. We have selected some of the most well-known lower extremity surgeons and teachers to contribute. Finally, we would like to acknowledge the tireless work of Lee Klein and his team at Springer for making this book a reality.

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Contributors

Peter B. Arnold, MD, PhD, FACS Division of Plastic and Reconstructive Surgery, University of Mississippi Medical Center, Jackson, MS, USA

Andrew Atia, MD Division of Plastic and Reconstructive Surgery, Duke University Medical Center, Durham, NC, USA

Saïd C. Azoury, MD Division of Plastic Surgery, University of Pennsylvania, Philadelphia, PA, USA

Derek E. Bell, MD Division of Plastic and Reconstructive Surgery, University of Rochester Medical Center, Rochester, NY, USA

Katherine C. Benedict, MD Division of Plastic and Reconstructive Surgery, University of Mississippi Medical Center, Jackson, MS, USA

Roger W. Cason, MD Division of Plastic, Maxillofacial, and Oral Surgery, Duke University Health System, Durham, NC, USA

Daniel J. Cunningham, MD, MHSc Department of Orthopaedic Surgery, Duke University, Durham, NC, USA

Mahendra Daya, MD Department of Plastic and Reconstructive Surgery, Inkosi Albert Luthuli Central Hospital, Mayville, South Africa

Artur Fahradyan, MD Division of Plastic and Reconstructive Surgery, University of Southern California, Los Angeles, CA, USA

Sean Figy, MD Department of Surgery, The University of Nebraska Medical Center, Omaha, NE, USA

Mark J. Gage, MD Department of Orthopaedic Surgery, Duke University, Durham, NC, USA

Benjamin Googe, MD Division of Plastic and Reconstructive Surgery, University of Mississippi Medical Center, Jackson, MS, USA

Trevor C. Hansen, MD Division of Plastic and Reconstructive Surgery, University of Rochester Medical Center, Rochester, NY, USA

Rachel E. Hein, MD Department of Surgery, Division of Plastic Surgery, Duke University Medical Center, Durham, NC, USA

Scott T. Hollenbeck, MD, FACS Division of Plastic and Reconstructive Surgery, Duke Medical Center, Durham, NC, USA

Matthew L. Iorio, MD Division of Plastic Surgery, University of Colorado Hospital, Aurora, CO, USA

Ryan C. Jefferson, MD Department of Plastic and Reconstructive Surgery, The Ohio State University Wexner Medical Center, Columbus, OH, USA

Franca Kraenzlin, MD Department of Plastic Surgery, Johns Hopkins Hospital, Owings Mills, MD, USA

Kate B. Krucoff, MD Division of Plastic and Reconstructive Surgery, Duke University Medical Center, Durham, NC, USA

Whitney O. Lane, MD Division of Plastic, Maxillofacial, and Oral Surgery, Duke University Medical Center, Durham, NC, USA

L. Scott Levin, MD, FACS Department of Orthopaedic Surgery, Department of Surgery (Plastic Surgery), University of Pennsylvania, Philadelphia, PA, USA

Howard Levinson, MD, FACS Departments of Surgery, Pathology, and Dermatology, Duke University Medical Center, Durham, NC, USA

Caitlin Elizabeth Marks Duke University School of Medicine, Duke University, Durham, NC, USA

David W. Mathes, MD Department of Surgery, Division of Plastic and Reconstructive Surgery, University of Colorado, Anschutz Medical Campus, Aurora, CO, USA

Benjamin McIntyre, MD, FACS Division of Plastic and Reconstructive Surgery, University of Mississippi Medical Center, Jackson, MS, USA

Suhail K. Mithani, MD Division of Plastic, Maxillofacial, and Oral Surgery, Duke University Health System, Durham, NC, USA

Lily R. Mundy, MD Division of Plastic and Reconstructive Surgery, Duke University, Durham, NC, USA

Jonah P. Orr, BS Division of Plastic, Maxillofacial, and Oral Surgery, Duke University Health System, Durham, NC, USA

Dennis P. Orgill, MD, PhD, FACS Division of Plastic Surgery, Brigham & Women's Hospital, Harvard Medical School, Boston, MA, USA

Ketan M. Patel, MD Division of Plastic and Reconstructive Surgery, University of Southern California, Los Angeles, CA, USA

Andrew L. Peredo, MD Department of Surgery, Division of Plastic and Reconstructive Surgery, University of Colorado, Anschutz Medical Campus, Aurora, CO, USA

Joon Pio (Jp) Hong, MD, PhD, MBA Department of Plastic and Reconstructive Surgery, Asan Medical Center, University of Ulsan College of Medicine, Seoul, South Korea

Bryan J. Pyfer, MD, MBA Division of Plastic Surgery, Duke University Hospital, Durham, NC, USA

Justin M. Sacks, MD, MBA, FACS Department of Plastic and Reconstructive Surgery, Johns Hopkins School of Medicine, Baltimore, MD, USA

Ronnie L. Shammas, MD Division of Plastic, Maxillofacial, and Oral Surgery, Duke University Health System, Durham, NC, USA

Somjade J. Songcharoen, MD Division of Plastic and Reconstructive Surgery, University of Mississippi Medical Center, Jackson, MS, USA

Hyunsuk Peter Suh, MD Department of Plastic and Reconstructive Surgery, Asan Medical Center, University of Ulsan College of Medicine, Seoul, South Korea

Mahsa Taskindoust Levine Science Research Center, Duke University, Durham, NC, USA

Rose Tillis, MD Division of Plastic and Reconstructive Surgery, Duke University Hospital, Durham, NC, USA

Ian L. Valerio, MD, MS, MBA, FACS Division of Burn, Wound, and Trauma, Departments of Plastic and Reconstructive, General, and Orthopaedic Surgery, The Ohio State University Wexner Medical Center, Columbus, OH, USA

Rebecca Vernon, MD Division of Plastic, Maxillofacial, and Oral Surgery, Duke University School of Medicine, Durham, NC, USA

Victoria Wickenheisser, MD Division of Plastic and Reconstructive Surgery, Duke University Hospital, Durham, NC, USA

Part I
Clinical

Chapter 1
Introduction to Lower Extremity Reconstruction: Historical Perspectives, Advances in the Field, and the Future

Saïd C. Azoury and L. Scott Levin

Reconstruction of the lower extremity has evolved as a separate discipline within reconstructive surgery. Trauma is the most common etiology for lower extremity wounds that require reconstruction, followed by tumor resection, infection, or underlying vascular disease. Patients with peripheral vascular disease or diabetes often develop wounds that require débridement, skeletal stabilization, and soft tissue coverage. Regardless of the etiology, the goal of reconstruction is to restore form as well as function.

S. C. Azoury
Division of Plastic Surgery, University of Pennsylvania, Philadelphia, PA, USA

L. S. Levin (✉)
Department of Orthopaedic Surgery, Department of Surgery (Plastic Surgery), University of Pennsylvania, Philadelphia, PA, USA
e-mail: Lawrence.Levin2@uphs.upenn.edu

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Background

Understanding the concept of the reconstructive ladder as it relates to the lower extremity is critical (Fig. 1.1) [1, 2]. Non-flap closure (*eg*, complex closure, grafting) or rotational flaps represent the lower rungs on the ladder and are most useful for smaller defects. For larger defects, free-tissue transfer may be the best option; it represents one of the higher rungs on the reconstructive ladder. The most common recipient site for free flap reconstruction of the leg is the distal third of the extremity, including the ankle and foot, where options for local flaps are limited. Further adding to the complexity of the treatment algorithm, the characteristics of a wound may alter the usual reconstructive options for any given location. For instance, a defect on the proximal third of the leg that is typically addressed with a pedicled gastrocnemius muscle flap may require free flap coverage in the setting of large composite-type defects.

Lower extremity reconstruction requires multidisciplinary care. Orthopaedic and plastic surgeons must be supported by musculoskeletal radiologists, vascular surgeons, infectious disease specialists, physical therapists, prosthetists, and specialized nursing staff [3]. In addition to the surgical treatment of lower extremity wounds, the psychosocial component is equally important, as the success of these patients depends on a strong support system. Psychiatrists and pain management are integral to any lower extremity treatment team. The reconstructed extremity must be able to bear weight, but not at the expense of insufferable pain. The postoperative phase is often the longest part of the treatment, and physical and occupational rehabilitation are fundamental to a successful recovery.

Historical Perspectives

The treatment of lower extremity wounds has evolved since the teachings of Hippocrates during Greece's Classical period nearly 2500 years ago. Similar to modern practice, fractures

FIGURE 1.1 Reconstructive ladder for lower extremity soft tissue defects

were stabilized with splints or external fixators, but soft tissue wounds were treated with ointments and potions. Hippocrates also described therapeutic amputation for vascular gangrene, while leaving the wound open to heal by secondary intention. Nearly four centuries later, Celsus wrote about the cardinal signs of inflammation: rubor, calor, dolor, tumor. He emphasized the need for early débridement of a wound, removal of foreign bodies, and hemostasis. In the mid sixteenth century, Ambroise Paré, a French surgeon considered one of the fathers of surgery, described the continuing pain of an amputated limb, so-called phantom limb. Pain continues to be a driver of discussion when considering early amputation and prosthetic fitting or complex limb salvage.

Significant progress in the field of lower extremity reconstruction was made in the twentieth century. Thomas Huntington (1849–1929) was well known for his contributions to aseptic surgery as well as the treatment of fractures. In 1905, he was presented with a challenging case of a young boy left with a substantial defect following radical debridement of tibial shaft osteomyelitis. He was the first to perform a pedicled vascularized fibula graft to reconstruct the defect. Around the same time, Alexis Carrel (1873–1944), a French surgeon and biologist, was studying various techniques in vascular surgery. In 1902, he reported the first end-to-end vascular anastomosis and introduced the concept of triangulation for vessel repair. He was awarded the Nobel prize in 1912 for his work, which set the foundation for the burgeoning field of microvascular reconstruction in the latter half of the twentieth century. Sir Harold Gillies (1882–1960) is widely accepted as the father of modern plastic and reconstructive surgery. Through his experience in treating wounded soldiers in World War I, he developed many of the techniques for reconstructing damaged tissues. Many believe that the so-called orthoplastic discipline traces back to 1919, when the Introduction for Gillies' plastic surgery textbook was written by an orthopaedic surgeon, Sir W. Arbuthnot Lane. In 1946, W.J. Stark described the first pedicled muscle flap to treat lower extremity osteomyelitis. In his experience, Stark observed that the use of a pedicled muscle flap along with débridement and antibiotics had double the success rate for treating chronic osteomyelitis, compared with no flap.

Countless advancements were made in vascularized bone, soft tissue flaps, and microsurgical techniques in the latter half of the twentieth century. In the late 1950s, Dr. Harry Buncke (1922–2008) served as a Senior Registrar at the Plastic Surgical and Burn Unit in Glasgow, Scotland. There, he was deeply influenced by Thomas Gibson (1915–1993) in vascular reconstruction and transplantation. Upon returning to the United States, he began using his newly acquired knowledge and made possible the replantation and transfer of tissues fed by 1-mm vessels. Around the same time, Julius Jacobsen and his student, Ernesto Suarez, found themselves dissatisfied with the magnification offered by surgical loupes. They introduced the operating microscope for small vessel anastomosis in 1960. In 1972, McGregor and Jackson described a new axial flap, the groin flap, and 1973, Rollin Daniel and G. Ian Taylor reported the first free groin flap transfer to cover a lower extremity soft tissue defect. In 1975, G. Ian Taylor described the first use of a free vascularized fibula for large segmental bone defects, which added yet another tool for the reconstructive surgeon. In an article that they coauthored, Daniel and Taylor opened by referencing Harry Buncke: "The successful transplantation of a block of composite tissue by reanastomosing the microvascular pedicle has untold experimental and clinical possibilities" [4]. The clinical impact of these historical milestones would soon be appreciated in the years that followed.

Composite vascularized tissue transfers became commonplace in the 1980s, and Marko Godina (1943–1986) was yet another pioneer in the field of lower extremity reconstructive microsurgery [5, 6]. His ideas lead to the first temporary ectopic implantation of an amputated hand and subsequent replantation after wound stability (Fig. 1.2). He also reported the first clinical use of free lateral arm flap, microvascular latissimus dorsi muscle flap, and saphenous neurovascular flap. In 1986, the year of his passing, he described the pathophysiology of

FIGURE 1.2 Dr. Marko Godina (*left*) was a pioneer in reconstructive microsurgery. His innovative ideas led to the first ectopic transplantation of a mutilated upper extremity for later replantation. (*Courtesy of* Photo Archive Medicina Danes)

high-energy trauma and advocated for radical débridement and early tissue coverage within the first 3 days after injury [7]. He also supported the practice of end-to-side anastomosis over end-to-end, in order to preserve distal blood flow in lower extremity microvascular reconstruction. These principles continue to guide our practice today.

Advances in the Field

Over the past several decades, the chronic complications of limb salvage surgery have been osteomyelitis and nonunion. The "Godina method" of treating complex lower extremity wounds with early radical débridement, skeletal fixation, and soft tissue coverage has stood the test of time in reducing these complications. Along with systemic antibiotics, the use of antibiotic-impregnated cement was introduced in order to administer antibiotics at higher concentrations locally than could be achieved via intravenous routes [5]. This method was used by orthopaedic surgeons in the 1970s and remains useful in lower extremity reconstruction.

Health care systems are becoming highly specialized in the coordinated care of patients requiring lower extremity reconstruction. The collaborative approach between orthopaedic and plastic surgeons for the past quarter of a century has evolved, resulting in a unique field of reconstructive surgery—orthoplastic surgery. Fellowships are now available to train not only aspiring microsurgeons, but also those individuals with a particular interest in orthoplastic surgery.

Advances in diagnostic imaging, such as CT angiography, MRI/MRA, and ultrasonography, have allowed for better detection of vascular compromise that should be addressed prior to reconstruction [8]. Many patients who require reconstruction for lower extremity wounds have underlying vascular disease. Impaired vascular flow also inhibits the healing of small defects secondary to trauma, surgical incisions, infection, or vascular ulcers, which may ultimately result in extensive defects that require free flap coverage. These imaging modalities also help to delineate the anatomy for choosing flap recipient vessels and provide information regarding superficial and deep venous outflow.

Negative pressure wound therapy (NPWT) was introduced in 1995 and has become widely embraced across various surgical specialties for acute and chronic wounds [9]. It has improved the management of lower extremity wounds and fracture care. NPWT can safely be placed on select composite defects and promotes formation of granulation tissue needed for skin grafting. NPWT functions to remove wound exudate, thereby optimizing conditions for wound healing. Although NPWT serves multiple purposes in the treatment of lower extremity wounds, it is never a substitute for vascularized tissue transfer. Dermal matrices were originally developed for burn reconstruction, but they are now used as an adjunct that can be employed to cover large areas of tissue with underlying exposed bone and tendon, which previously were not considered amenable for skin grafting. When applied to superficial wounds, the aesthetic results are comparable to other methods of reconstruction.

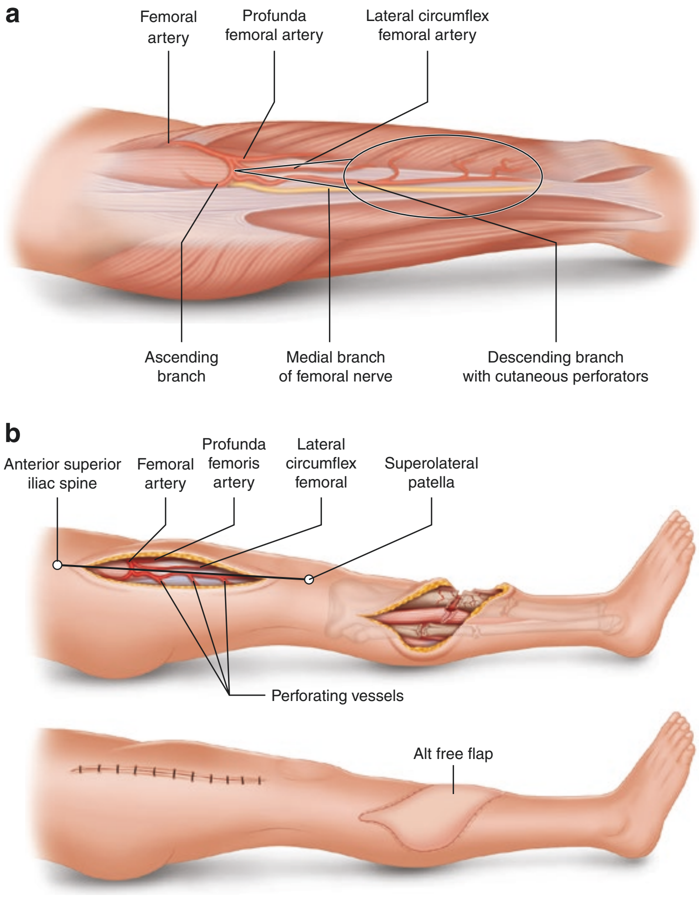

Figure 1.3 Use of perforator flap, specifically the fasciocutaneous anterolateral thigh (ALT) flap, for lower extremity trauma reconstruction. (**a**), The anterolateral thigh flap is based on the descending branch of the lateral femoral circumflex artery. The advantages of using ALT perforator flap (**b**) include reduced donor site morbidity, with an incision that can often be closed primarily, as well as a large skin paddle for coverage

The increased use of perforator flaps has revolutionized the reconstructive armamentarium (Fig. 1.3). Perforator flaps reduce donor site morbidity and have improved overall patient satisfaction following limb salvage. Greater attention is being paid to improving the aesthetics of reconstructive efforts, using techniques such as endoscopic tissue expansion to release contractures or remove skin grafts that were used to close fasciotomy wounds.

Future Directions

Even with the advances that have been made in lower extremity reconstruction, efforts may fail as a result of risks described nearly a century ago. Continuing to critically review limb salvage techniques will provide additional evidence to guide practice. Strengthening infrastructure for reconstruction has been shown to correlate with improved outcomes and decreased costs. Promoting the value of a multidisciplinary approach, specifically orthoplastic surgery, will result in a higher rate of successful limb salvage in patients at risk for amputation.

The success of prosthetics and composite tissue allotransplantation will have a significant impact on the long-term future of lower extremity reconstruction. Although we are making progress in upper extremity transplantation, lower extremity transplantation at this time does not justify the risks associated with long-term immunosuppression. When considering the most severe cases of trauma, outcomes following salvage are similar to those after amputation, and decision-making continues to be guided by patient preference and provider expertise. Scoring systems have been developed as a way to assist the surgical team in deciding on amputation versus salvage [10], but their clinical utility has not been validated. A future goal should be to better predict those who would perform better with reconstruction or amputation and prosthesis. Until amputation and myoelectric prosthesis prove to be functionally better, safer, and more cost-effective than limb salvage, reconstruction will continue to be a viable option preferred by many patients. For this reason, plastic and orthopaedic surgeons must continue to be trained in complex and microsurgical reconstruction in order to be prepared to deliver the best care possible to these patients. The following chapters provide a comprehensive guide to lower extremity reconstruction, with detailed descriptions of the various approaches used based on the wound characteristics and location.

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Chapter 2
Essential Anatomy of the Lower Extremity

Artur Fahradyan and Ketan M. Patel

The lower extremity is often involved in trauma or other disease processes requiring reconstructive procedures in an attempt to maintain its anatomic and functional integrity. It also serves as a donor site for free flaps to reconstruct other body parts. Therefore, understanding the complex anatomy of the lower extremity is fundamental for every reconstructive surgeon to learn and understand. The aim of this chapter is to review the essentials of skeletal, muscular, fascial, and important neurovascular anatomic structures of the thigh, leg, and foot.

The Thigh

The thigh is an important tissue donor for commonly used local, regional, and free flaps, such as the gracilis and sartorius muscle flaps, and various perforator flaps. Therefore, knowing the thigh anatomy helps us to harvest these flaps for many reconstructive procedures.

A. Fahradyan · K. M. Patel (✉)
Division of Plastic and Reconstructive Surgery, University of Southern California, Los Angeles, CA, USA

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Thigh Skeletal Structure

The borders of the thigh extend from the infragluteal crease and the inguinal ligament to the tibiofemoral joint. The skeletal structure of the thigh is made up of a single femoral bone, which articulates with the pelvic acetabulum proximally in the hip joint, and with the tibia and the patella distally to make up the knee joint [1–4]. The femur receives direct endosteal and periosteal blood supply from multiple sources, but the most clinically relevant in terms of tissue reconstruction is the genicular arterial system to the distal metaphyseal region. Periosteum, cortical, and cancellous bone can be harvested from the medial femur as a vascularized flap using the descending genicular artery [2]. It is utilized as a free flap in treatment of bony nonunions of the clavicle, humerus, tibia, and radius.

Thigh Fascial Layers

The thigh has a superficial fascia and deep fascia. The superficial fascia lies within the subcutaneous fat, and the deep fascia lies below it. The deep fascia, also called the *investing fascia of the thigh* or *fascia lata*, encircles the thigh muscles. The superficial and deep fascial layers join at the inguinal ligament. The great saphenous vein, superficial branches of the femoral artery, and the lymphatic vessels transition from deep to superficial in this region, passing through the fossa ovalis, which is an opening in both fascial layers. The iliotibial tract, a thickening of the lateral aspect of the deep fascia that is attached to the tensor fascia latae muscle proximally, aids in maintaining knee extension [1–4].

Septa pass from the deep fascia to the femur, confining the thigh musculature within three compartments: anterior, posterior, and medial or adductor. It should be noted, however, that only the anterior and posterior compartments have fascial boundaries, whereas the adductor compartment is not a true anatomic compartment.

Thigh Musculature

The anterior (extensor) thigh compartment contains the following muscles:

- sartorius
- quadriceps femoris, which is composed of the rectus femoris, vastus lateralis, vastus intermedius and vastus medialis muscles (Table 2.1, Fig. 2.1).

The anterior compartment muscles extend the lower leg at the knee joint. In addition, the sartorius and rectus femoris muscles flex the thigh at the hip joint.

The sartorius muscle is a source for a commonly used local muscle and is often transposed to cover the proximal thigh wound with femoral vessel exposure. It is the most superficial muscle of the thigh and obliquely crosses the thigh from superolateral to inferomedial. The muscle originates from the anterior superior iliac spine and inserts on the proximal medial surface of the tibia. This is also an insertion point for the gracilis and semitendinosus muscles forming the pes anserinus [3, 4].

The quadriceps muscle originates from the femoral shaft. Its distal end makes up the quadriceps tendon, which crosses over the patella to become the patellar tendon and inserts onto the tibial tuberosity. One portion of the muscle can be removed to be used as a tissue donor. This is usually well tolerated with centralization of the remaining muscles and appropriate physical therapy. A portion of the vastus lateralis muscle is often taken with the anterolateral thigh flap, or the rectus femoris is used as a local flap with minimal or no functional deficit of the knee [5].

The posterior (flexor) thigh compartment contains these muscles:

- semitendinosus
- semimembranosus
- biceps femoris

Table 2.1 Overview of thigh musculature

	Muscle	Origin	Insertion	Function	Blood Supply	Innervation
Anterior compartment	Sartorius	Anterior superior iliac spine	Proximal medial tibia	Knee flexion and internal rotation Hip flexion, abduction and external rotation	SFA	Femoral
	Rectus femoris	Anterior superior iliac spine and ileum	Quadriceps tendon	Knee extension Hip flexion	LCFA SFA	Femoral
	Vastus lateralis	Femoral shaft	Quadriceps tendon	Knee extension	LCFA Direct branch from profunda femoris Superior genicular artery	Femoral
	Vastus medialis	Femoral shaft	Quadriceps tendon	Knee extension Patellar stabilization	SFA Descending genicular artery	Femoral
	Vastus intermedius	Femoral shaft	Quadriceps tendon	Knee extension	Direct branches from profunda femoris	Femoral