Christopher C. Kaeding
James R. Borchers *Editors*

Hamstring and Quadriceps Injuries in Athletes

A Clinical Guide

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To my wife, Christine, for her endless source of patience and support of my academic career in sports medicine with all its time demands, off hours obligations, and unexpected interruptions.
To my mentor, John Bergfeld, M.D., for his guidance, advice, encouragement, and "prodding." Without his influence and mentoring, my career and this book would not have happened.

Christopher C. Kaeding, MD

To my family—Mary, Emily, William, and Joseph—your love and support are my inspiration and foundation.

James R. Borchers, MD, MPH

Preface

This textbook is dedicated to the teams of physicians, athletic trainers, orthopaedists, coaches, physical therapists, and other clinicians who care for the physically active, but most importantly, to all the athletes who have sustained or struggled with an injury to the quadriceps or hamstrings. Though many of these injuries are self-limiting, many require surgical intervention and can have devastating consequences to an athletic career. In today's world with the ever-expanding emphasis on training, exercise, and performance, quadriceps and hamstring injuries are not uncommon. With society's expectation of quick and complete recovery, a complete understanding of these injuries is key to maximize recovery and minimize long-term impairment. Editing this textbook has been most rewarding as the authors responded and produced their respective chapters. We would like to acknowledge our appreciation of the authors for taking the time and effort to share their expertise, experience, research, and clinical pearls in the evaluation and treatment of quadriceps and hamstring injuries in athletes. This book is intended to be a current summation of the basic science and epidemiology of these injuries as well as a summary of the current best practices for the evaluation and treatment of these soft tissues about the thigh. This text is focused on material relevant to the clinician, and it is our most sincere hope that this text is of great value to not only clinicians, but students, coaches, and athletes as well.

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Abbreviations

AAROM	Active assistive range of motion
ACL	Anterior cruciate ligament
ACP	Autologous conditioned plasma
AIIS	Anterior inferior iliac spine
AMI	Arthogenic muscular inhibition
AROM	Active range of motion
CI	Confidence interval
EGF	Epidermal growth factor
EMG	Electromyographic
ESWT	Extra-corporeal shockwave therapy
FGF	Fibroblast growth factor
FMS	Functional Movement Screen
H/Q	Ratio hamstrings to quadriceps ratio
HBO	Hyperbaric oxygen
LSI	Limb symmetry index
MCL	Medial collateral ligament
MDSCs	Muscle-derived stem cells
MO	Myositis ossificans
MPFL	Medial patellofemoral ligament
MRI	Magnetic resonance imaging
MVIC	Maximum voluntary isometric contraction
NMES	Neuro-muscular electrical stimulation
NSAIDs	Non-steroidal anti-inflammatory drugs
PDGF	Platelet-derived growth factor
PMN	Polymorphonuclear neutrophils
POL	Posterior oblique ligament
PRC	Platelet-rich concentrate
PROM	Passive range of motion
PRP	Platelet-rich plasma
RICE	Rest, ice, compression and elevation
ROM	Range of motion
SD	Standard deviation
SLR	Straight leg raises
SMD	Standardized mean difference
TGF-β	Transforming growth factor-beta

UBE	Upper body ergometer
VEGF	Vascular endothelial growth factor
VML	Vastus medialis longus
VMO	Vastus medialis obliquus
WBAT	Weight bearing as tolerated

1 Functional Anatomy of the Hamstrings and Quadriceps

Nathan J. Kopydlowski, Alexander E. Weber, and Jon K. Sekiya

Introduction

The hamstring and quadriceps muscle complexes are integrally involved in the kinetic chain of the lower body. At rest these two muscle complexes stabilize the hip and knee joints. Once the athlete is in motion, these two opposing groups of muscles work in concert to produce coordinated lower extremity movement during gait and athletic activity. The high frequency of activation for both the hamstring and quadriceps complexes leads to high susceptibility to injury, and the ramification of such injuries can have a substantial effect on the ability of the athlete to compete at his or her highest level. Understanding the functional anatomy of the hamstring and quadriceps muscle complexes affords the physician the ability to systematically evaluate and identify potential pain generators and ultimately develop the most appropriate treatment plan.

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Hamstrings

Normal Anatomy

The hamstring muscle complex is composed of three distinct muscles—the biceps femoris, semimembranosus, and semitendinosus—which are involved in knee flexion and hip extension (Fig. 1.1). To function as such the hamstring muscle complex crosses both the hip and the knee joints. All muscles are innervated by the tibial division of the sciatic nerve, with the exception of the short head of the biceps femoris muscle, which is innervated by the peroneal branch of the sciatic nerve. The hamstring muscle complex receives its blood supply from the deep femoral artery. The deep femoral artery branches off of the main femoral artery soon after its origin and runs on the posterior side of the adductor longus before it gives off branches that include the lateral femoral circumflex, medial femoral circumflex, and perforating arteries to the hamstring muscles.

Biceps Femoris

The biceps femoris muscle is located on the posterolateral aspect of the thigh. It originates from two locations, with the long head originating

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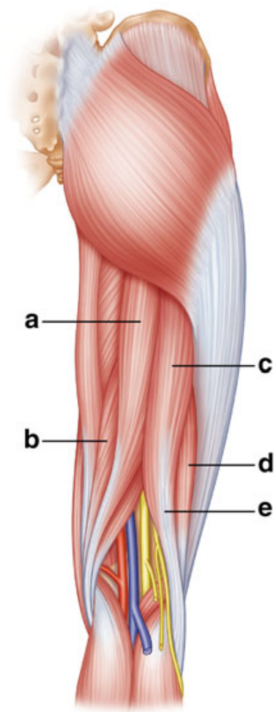

Fig. 1.1 Illustration of the posterior thigh demonstrating the hamstring gross anatomy. The hamstrings lie in the superficial muscle layer of the posterior thigh, with the semitendinosus (*A*) and semimembranosus (*B*) on the medial side and the long head (*C* and *E*) and short head (*D*) of the biceps femoris on the lateral side of the posterior thigh

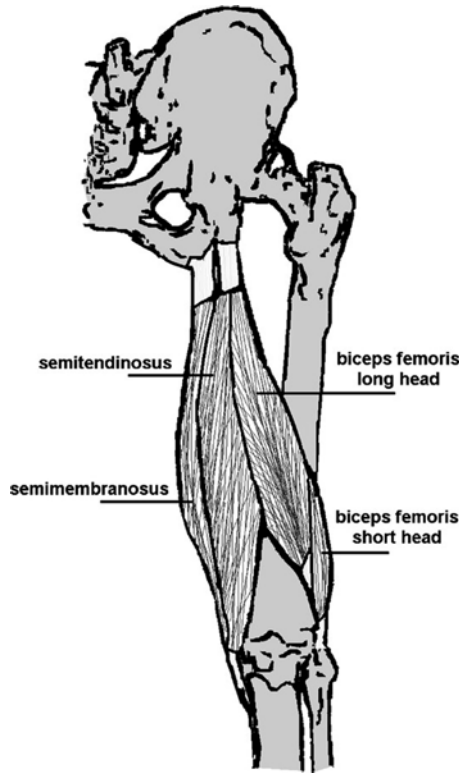

Fig. 1.2 Illustration of the hamstring origins. The semitendinosus, the semimembranosus, and the long head of the biceps femoris originate from the ischial tuberosity. The short head of the biceps femoris originates from the lateral supracondylar ridge of the femur. With kind permission from Springer Science + Business Media: Skeletal Radiology, MR observations of long-term musculotendon remodeling following a hamstring strain injury, 37(12), 2008, Amy Silder

from the medial facet of the ischial tuberosity and the short head arising from the lateral supracondylar ridge of the femur and the middle third of the linea aspera (Fig. 1.2). The short head of the biceps femoris follows a path distally and laterally at a 30° angle to the coronal plane of the femur and a 45° angle to the sagittal plane of the femur when the knee is flexed to 90° (Fig. 1.3) [1]. The origin of the short head of the biceps femoris on the femur is often used as a landmark to classify a hamstring injury as proximal or distal [2]. The short head of the biceps femoris muscle is innervated by the common peroneal division of the sciatic nerve, while the long head is innervated by the tibial division of the sciatic nerve (both L5 and S1 nerve roots) [3].

An understanding of the tendinous insertion points of the long and short heads of the biceps femoris is crucial for appreciating the biomechanics of the posterolateral corner of the knee. Acute injuries to the biceps femoris muscle and subsequent insertion points can lead to acute knee instability [4–6]. The tendinous insertion components of the long head of the biceps femoris begin to form proximal to the knee and then divide into two tendinous components (the direct and anterior arms) and three fascial components (the reflected arm, the lateral aponeurosis and the anterior aponeurosis) at the knee [1]. Terry et al. have shown that the direct arm inserts at the posterolateral edge of the fibular head at a point lateral to the fibular styloid, while the anterior arm inserts on the lateral edge of the fibular head [1].

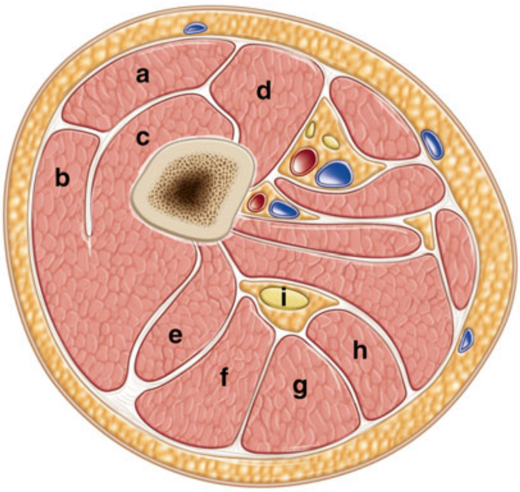

Fig. 1.3 Cross-section of the gross anatomy of the mid-thigh. The quadriceps muscle complex [rectus femoris (*A*), vastus lateralis (*B*), vastus intermedius (*C*), and vastus medialis (*D*)] runs along the anterior and lateral aspect of the femur. The hamstring muscle complex [short (*E*) and long (*F*) head of the biceps femoris, semitendinosus (*G*), and semimembranosus (*H*)] runs along the posterior aspect of the femur surrounding the sciatic nerve (*I*)

The reflected arm of the fascial components originates from the tendon just proximal to the fibular head and inserts to the posterior edge of the iliotibial tract [1]. The lateral aponeurotic expansion attaches to the tendinous anterior arm and covers the fibular collateral ligament, while the anterior aponeurotic expansion covers the anterior compartment of the leg [1]. The short head of the biceps femoris has a muscular attachment to the anterior and medial sides of the distal long head tendon. There are also tendinous attachments to the posterolateral joint capsule at the level of the posterior horn of the lateral meniscus (a capsular arm), the fibular head (direct arm), and the lateral tibial tuberosity 1 cm posterior to Gerdy's tubercle (anterior arm) [1, 7]. The other significant insertion of the short head is an attachment of the capsuloosseous layer to the iliotibial tract that forms a biceps–capsuloosseous iliotibial tract complex [1].

Understanding the anatomical relationships of the components of the biceps femoris muscle complex is very important in developing an understanding of their role in stability of the knee. Studies have shown that injuries to the biceps femoris tendons have been seen in conjunction with lateral ligamentous injuries of the knee and anterolateral–anteromedial rotary instability of the knee [8, 9]. A study by Terry et al. [1] has shown that the short head of the biceps femoris muscle is more commonly injured than the long head. The injuries most commonly seen include avulsions of the capsular arm followed by injuries to the biceps–capsuloosseous complex. Other avulsion injuries are seen at the insertion of the anterior arm of the short head at the lateral tibial tuberosity [1]. It has also been proposed that the dual innervation of the biceps femoris muscle may lead to desynchronized firing of this muscle, and this could be one of the underlying reasons that it is the most commonly injured muscle in the hamstring muscle complex [10, 11]. The biceps femoris muscle complex is a very important dynamic knee stabilizer and repair or reconstruction of the tendinous and facial insertion components should be taken into account when patients present with knee instability.

Semitendinosus Muscle

The semitendinosus muscle receives its name from the substantial tendonous component to the overall size of the musculotendinous unit. This muscle originates from the inferomedial side of the ischial tuberosity as part of a conjoint tendon that also includes the long head of the biceps (see Fig. 1.2) [3]. The conjoint tendon is oval in shape and measures 2.7 cm superoinferiorly and 1.8 cm transversely on average [12]. The semitendinosus muscle has a complex tendinous intersection that separates the muscle into inferior and superior regions that are innervated by separate branches of the tibial nerve [13]. It has been postulated that the superior region may specifically function in driving motion at the hip while the inferior region may specifically function in driving motion at the knee [14].

At the more distal aspects of the semitendinosus, the muscle forms a long round tendon at the midpoint of the thigh that runs along the medial side of the popliteal fossa. The tendon follows a path around the medial tibial condyle and then passes over the medial collateral ligament, and inserts on the superomedial surface of the tibia. The semitendinosus, gracilis, and sartorius muscles all contribute to the pes anserinus on the anteromedial surface of the proximal tibia, and their corresponding bursae can be a source of pain due to pes anserinus bursitis [3]. The long length of the tendon of this muscle has been thought to predispose this muscle to rupture [15]. Additionally, the semitendinosus tendon is often harvested for anterior cruciate ligament (ACL) reconstruction, and though it has been shown to regenerate to a certain degree, the distal aspect appears to reinsert on the gastrocnemius fascia rather than the tibia.[16]. This can occasionally lead to ineffective scar formation and, in turn, hamstring weakness and recurrent injury in the high-level athlete [16, 17].

Semimembranosus Muscle

The semimembranosus muscle originates from the ischial tuberosity at a point that is superior and lateral to the biceps femoris and semitendinosus muscles. The origin of the semimembranosus tendon is crescent shaped and extends superoinferiorly over 3 cm and transversely over 1 cm (see Fig. 1.2) [12]. The proximal tendon follows a course that travels medial and anterior to the other muscles of the hamstring complex (see Fig. 1.3). The proximal tendon is an elongated structure with fibrous connections to the origin of the biceps femoris and adductor magnus tendons [3]. The tendinous origin of the semimembranosus is the longest of the proximal hamstring tendons, averaging 31.9 cm in cranial–caudal length, and becomes aponeurotic soon after its origin [13]. Distally the muscle is composed of numerous short unipennate and multipennate fibers, which maximize the number of muscle fibrils per unit area [18]. The semimembranosus muscle belly is the largest of the hamstring muscle complex averaging 15.7 cm^2 in its midsubstance. This large area allows for the muscle to generate the greatest force but at the slowest velocity of all the hamstring muscles [19]. Distally, the muscle inserts primarily on to the posterior medial aspect of the medial tibial condyle, with multiple tendon slips that expand across the medial aspect of the knee and attach to various soft tissue support structures of the knee.

The multiple insertion points of the semimembranosus are important contributors to the stability of the posteromedial corner of the knee [18, 20, 21]. There are discrepancies as to how many insertion points or "arms" are formed from the distal tendon of the semimembranosus. LaPrade et al. [22] have attempted to create a common terminology and description of the anatomy of these insertion points. Generally there is agreement on three arms: the direct arm, the anterior arm, and the expansion in the oblique popliteal ligament [22]. The direct arm of the insertion follows an anterior course deep to the anterior arm and inserts on the posterior medial aspect of the tibia. The anterior or tibial arm extends anteriorly under the posterior oblique ligament and inserts on the proximal tibia inferior to the tibial collateral ligament [22]. The oblique popliteal ligament is a broad, thin lateral continuation of the semimembranosus tendon that becomes part of the posterior medial capsule [22].

LaPrade and colleagues [22] have also described multiple additional insertions: the distal tibial arm (also referred to as popliteal aponeurosis), the components of the posterior oblique ligament, the meniscal arm, and the proximal posterior capsular arm. The distal tibial arm is an expansion of the semimembranosus that forms a facial layer over the popliteus muscle belly [22]. The fibrous sheath of the semimembranosus tendon extends anteriorly and contributes to the posterior oblique ligament and is thought to act as a secondary stabilizer to posterior tibial translation [23]. The meniscal arm is described as a short band-like connection between the tendon and the meniscotibial band at the posterior horn of the medial meniscus, and is thought to prevent impingement of the posteromedial meniscus during flexion [24]. The proximal posterior capsular arm has been shown to course along the superior aspect of the oblique popliteal ligament and ends with several fine attachments to the posterior capsule [22, 25]. These insertions all work together to stabilize the posterior medial corner of the knee and should be taken into account when evaluating the patient with posteromedial knee instability.

Muscle Composition

The muscles of the hamstring complex all have distal tendons that originate from deep within the muscle belly and run close to the entire length of the muscle and then emerge at the distal end of the muscle–tendon unit as distinct tendonous structures [20]. These long tendons help to develop a "spring" effect that accentuates performance during athletics; however, this ability may also be a detriment as the "spring" effect leads to increased susceptibility to injury [26]. The tendons are attached to the muscle fibers in a pennate arrangement on the central tendon [20]. The distal myotendinous junction has been described as the weakest link in the muscle–tendon–bone complex, and as a result is a common region of injury [2].

The muscle and tendon structure of the hamstring complex creates three distinct areas within each muscle–tendon unit where the different physical properties of tissues interact, resulting in areas susceptible to eccentric injuries [10, 27–29]. The first of these distinct areas is the myotendinous junction, the point where the distal and proximal tendons emerge from the muscle belly. The second is the myofascial junction, the location at which the muscle fibers connect to the aponeurotic fibrous layer surrounding each of the muscle bellies. Lastly, the intramuscular myotendinous junction runs along a large portion of the muscle belly [2]. It is important to know that in the skeletally immature athlete the ischial apophysis is the weakest point of the hamstring muscle–tendon unit until the secondary ossification center of the ischium is closed sometime between the 15th and 25th years of life [26]. Understanding the basic anatomy and the locations predisposed to injury can assist the treating physician with appropriate diagnosis and treatment.

Variant Anatomy

There are a number of commonly described anatomic variants to the hamstring complex. The biceps femoris muscle has been described with variant origins on the ischial tuberosity [21]. The semimembranosus muscle has also been documented as hypoplastic or absent in some cases, while others have documented hypertrophic tendon slips [30, 31]. Injury may result due to weakened muscle–tendon units or decreased flexibility secondary to hypertrophic tendon slips. Hamstring variant anatomy is typically diagnosed on ultrasound or magnetic resonance image (MRI) and knowledge of such variations is crucial for guiding diagnosis and must be appreciated if operative intervention is to be conducted [21, 30].

Biomechanics

The muscles of the hamstring complex work together to both extend the hip and flex the knee during the gait cycle. During the swing phase of the gait cycle the hamstring muscles coordinate extension at the hip and prevent extension at the knee [21]. The hamstring complex is also involved in external and internal rotation of the leg due to the obliquity of the biceps femoris and semitendinosus, respectively, when the knee is in a flexed position [21].

The hamstring complex also plays an important role in stabilizing the hip joint. The inferior origin of the hamstring muscles within the pelvis, but at the level of the hip joint, also assists in stabilizing the hip joint. The length of the hamstring muscle complex limits the range of motion of the hip in a way that prevents full hip flexion unless the knee is in the flexed position. As a result, forward swing of the thigh results in passive flexion of the knee and protects the hamstrings from strain due to overextension injuries during the swing phase of the gait cycle [32]. This mechanism of protection breaks down when an athlete is sprinting at full stride, attempting to over stride, or when his or her foot hits the ground. At this vulnerable position the hamstring muscle