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.

Columbus, OH, USA

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James R. Borchers, MD, MPH

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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

Functional Anatomy of the Hamstrings and Quadriceps

1

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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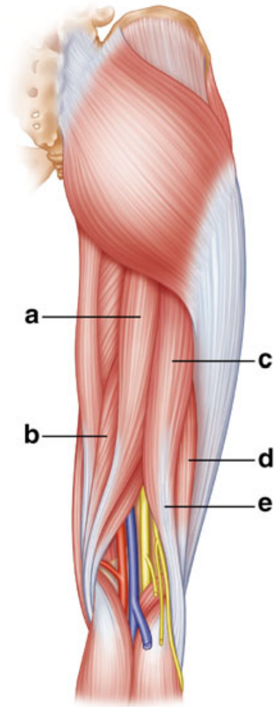

Fig. 1.1 Illustration of the posterior thigh demonstrating the hamstring gross anatomy. The hamstrings lie in the superficial muscle layer of the posterior thigh, with the semitendinosus (*A*) and semimembranosus (*B*) on the medial side and the long head (*C* and *E*) and short head (*D*) of the biceps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

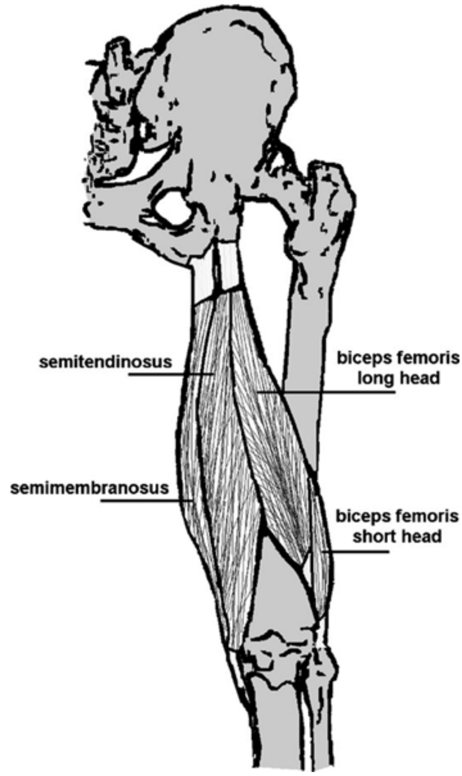

Fig. 1.2 Illustration of the hamstring origins. The semitendinosus, the semimembranosus, and the long head of the biceps femoris originate from the ischial tuberosity. The short head of the biceps femoris originates from the lateral supracondylar ridge of the femur. With kind permission from Springer 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].

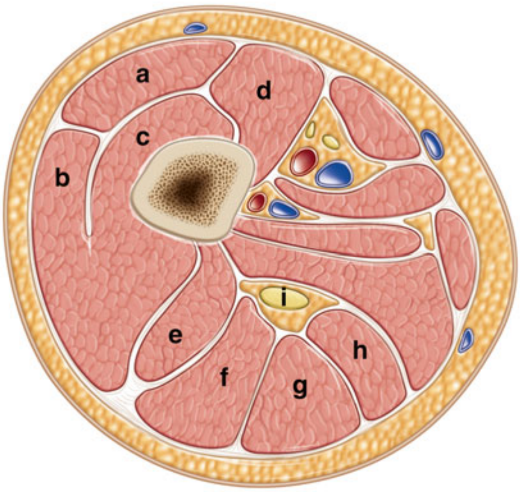

Fig. 1.3 Cross-section of the gross anatomy of the mid-thigh. The quadriceps muscle complex [rectus femoris (*A*), vastus lateralis (*B*), vastus intermedius (*C*), and vastus medialis (*D*)] runs along the anterior and lateral aspect of the femur. The hamstring muscle complex [short (*E*) and long (*F*) 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 complex is at its point of both maximal lengthening and maximal muscle unit contraction, leading to eccentric firing of the muscle and increased risk of injury [33, 34].

The hamstring muscle complex plays a large role in the stabilization of the posterolateral corner of the knee. In knee flexion the insertion of the biceps femoris on the iliotibial tract and fibular collateral ligament helps to keep the iliotibial tract tight during knee flexion. This assists with knee stability under varus loads [35]. The hamstring insertion at the fibular collateral ligament has been shown to help keep the collateral ligament taut during the full range of knee flexion, while the insertion at the posterior capsule contributes to the posterior pull of the capsule during knee flexion contributing to capsular stability [35].

The multiple insertion points of the semimembranosus are also paramount for stabilization of the posteromedial corner of the knee [23]. These insertions strengthen the stability of the knee under valgus load and have a small but mentionable role in prevention of ACL and posterior cruciate ligament reconstruction failure if injuries to the posteromedial corner are recognized preoperatively [23]. The contribution of the semimembranosus insertion on the posterior oblique ligament (POL) has a large effect on the stability of the posteromedial corner of the knee during the full range of knee motion [36, 37]. It is a primary stabilizer against internal rotation of the knee in full extension, but also contributes to the stability through all knee flexion angles [37]. The POL functions by sharing the forces on the medial collateral ligament (MCL) with internal and external rotation, valgus stress, and anterior and posterior tibial translation of the knee [36, 37].

The hamstring muscles also act in conjunction with the ACL to prevent anterior tibial translation during the heel strike portion of the gait cycle. A study by Li et al. has shown that the combination of both hamstring and quadriceps co-contraction can reduce the in-situ forces on the ACL at various points during the gait cycle [38]. Increasing the strength of the hamstring muscle complex has been shown to decrease ACL strain, and as a result some have advocated for training programs focused on hamstring strengthening to prevent ACL ruptures [39, 40].

Injury to the hamstring muscle–tendon unit during the gait cycle is due to the contraction of the antagonistic hamstrings and quadriceps muscle complexes and the imbalance in muscle strength, with quadriceps muscle being stronger. These conditions result in forced hip flexion with the knee held in extension [21, 28, 41]. The sudden functional change of the muscle complex from dynamic stabilizer to rapid contractor has been thought to be the cause of hamstring injuries at this stage of the gait cycle [42]. Another possible cause for hamstring injury is the aforementioned biarticular design of the hamstring muscle complex. Due to this design the hamstring muscles are not able to act on one joint without stabilizing the other joint. This results in the muscle complex having to absorb and counteract these multiple competing forces, leaving the hamstring muscle complex susceptible to injury [15, 42]. Compensatory injury to the hamstring complex has also been described in athletes with deficiencies in the surrounding joints. In cases of athletes with femoroacetabular impingement, the demand for motion at the hip may exceed the functional range of motion. In this case the athlete may recruit adjacent muscles and joints to provide the necessary excess motion, which can injure the hip joint and adjacent muscles [43].

Quadriceps

Normal Anatomy

The quadriceps muscle complex consists of the rectus femoris, the vastus medialis, the vastus lateralis, and the vastus intermedius (Fig. 1.4). The quadriceps are the primary extensors of the knee and all are innervated by the femoral nerve (L2-4 nerve roots) and receive their blood supply from the common femoral and deep femoral arteries [3]. The quadriceps muscle complex is one component of the extensor mechanism. The additional extensor mechanism components include the quadriceps tendon, patella, patellar tendon,

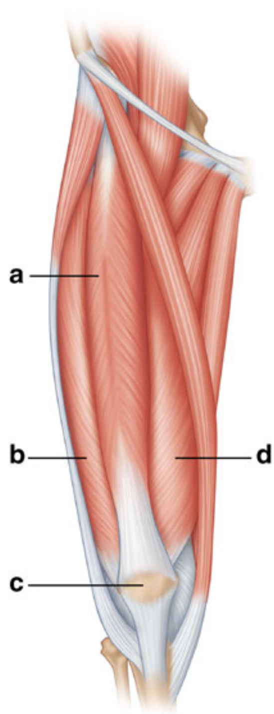

Fig. 1.4 Illustration of the anterior thigh demonstrating the quadriceps gross anatomy. The quadriceps muscle complex lies along the anterior thigh. The rectus femoris (*A*) is the most superficial with the vastus lateralis (*B*) and the vastus medialis (*D*) on the lateral and medial sides of the thigh, respectively. The quadriceps muscle complex inserts on the patella (*C*) and ultimately onto the tibial tubercle via the patellar tendon

and patellar retinaculum. All of these structures work in concert to provide knee extension.

Rectus Femoris

The rectus femoris muscle is the only muscle of the quadriceps muscle complex to cross two joints. One head of the muscle originates from the anterior inferior iliac spine (the direct head) and the other head (the reflected or indirect head) originates from the ilium superior to the acetabulum [3]. The rectus femoris lies on top of the vastus intermedius and is the most superficial muscle of the anterior compartment (see Figs. 1.2 and 1.3). The true insertion of the rectus muscle is the tibial tubercle through confluents with the patellar ligament, but in some literature the insertion is described to be at the patella as a common tendon with the vastus muscles [44]. The rectus femoris inserts on the anterior portion of the base and the superior third of the anterior surface of the patella, with some portions contributing to the patellar tendon [45–47].

Vastus Medialis

The vastus medialis runs along the medial side of the extensor compartment of the anterior thigh (see Fig. 1.4). The muscle originates from the intertrochanteric line and the medial lip of the linea aspera of the femur, and the muscle inserts on to the superior medial border of the patella via the quadriceps tendon. The muscle is composed of an oblique portion and a longitudinal portion referred to as the vastus medialis obliquus (VMO) and vastus medialis longus (VML), respectively. The VMO arises from the tendon of the great adductor muscle and inserts on the medial and superior borders of the patella at an angle between 50° and 55° [48]. Weakness, atrophy, and variations in the attachment location of the VMO have all been shown to be causes of patellofemoral instability and maltracking [47, 49, 50]. This often leads to anterior knee pain and instability, thus strengthening of the VMO must be an integral part of the physical therapy and rehabilitation protocols when such pathology is suspected.

Vastus Lateralis

The vastus lateralis muscle belly runs along the lateral side of the anterior compartment of the thigh (Fig. 1.5). Studies have shown that the vastus lateralis originates from the greater trochanter and the lateral lip of the linea aspera of the femur, with some fibers that also originate from the lateral intermuscular septum [51]. Similar to the vastus medialis, the vastus lateralis has been described as having two distinct regions with two distinct tendons: the vastus lateralis longus and vastus lateralis oblique [52]. The two tendons

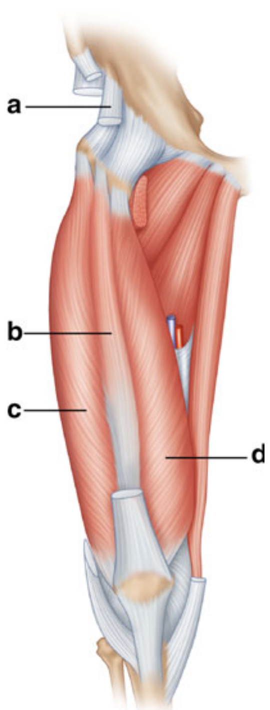

Fig. 1.5 Illustration of the anterior thigh with rectus femoris reflected. The direct head of the rectus femoris originates at the anterior inferior iliac spine (*A*). The vastus intermedius (*B*) runs inferior to the rectus femoris and between the vastus lateralis (*C*) and the vastus medialis (*D*)

combine to form a common tendon that inserts at the base and the superolateral border of the patella [52]. The vastus lateralis obliquus in combination with the lateral patellar retinaculum is responsible for the lateral force that counteracts the VMO to stabilize the patella during flexion and extension of the knee [53].

Vastus Intermedius

The vastus intermedius is the deepest muscle of the quadriceps muscle complex and wraps around the lateral side of the femur (see Fig. 1.3). The muscle originates from the superior two-thirds of the anterior and lateral surfaces of the proximal femoral shaft and the fibers run distally to insert on the deep aspect of the superior border of the patella (see Fig. 1.5). Some of the fibers of the vastus intermedius have also been shown to originate from the lateral intermuscular septum [54]. The vastus intermedius helps to extend the knee and is innervated by the femoral nerve. Studies have shown that the vastus intermedius muscle is the most efficient extender of the knee and is responsible for the final 15° of knee extension [54, 55].

Quadriceps Tendon

The quadriceps tendon is composed of the four muscular components of the extensor mechanism that fuse 2 cm proximal to the patellar tendon [45–47, 49]. While some authors describe the quadriceps tendon as one structure that attaches to the sides and base of the patella [56], others describe the tendon as being comprised of three layers that crisscross and insert into the proximal patella [45, 46]. The superficial layer originates from the deep fascia of the rectus femoris, while the intermediate layer originates from the deep fascia of the vastus lateralis and medialis muscles, and finally the deep layer comes from the anterior fascia of the vastus intermedius muscle [57]. These studies have shown that there are variations among individuals as to how many layers are present as well as the fascial contributions to each layer [57]. The individual variations in these lamina have been postulated to affect patellar motion during the different portions of the flexion arc of the knee, potentially predisposing patients to patellofemoral joint instability and pain [44]. The anatomy and biomechanics of the quadriceps tendon have a large impact on the stability of both the tibiofemoral and the patellofemoral joints. In cadaveric models the magnitude of quadriceps contraction has been positively correlated with the amount of patellofemoral joint stability [44]. Lastly, the central third of the quadriceps tendon has been used as a viable soft tissue or soft tissue–bone autograft in knee reconstructive surgery. If a bone plug is to be harvested with the quadriceps tendon graft, Scully et al. [58] have described a technique that shifts the soft tissue harvest medial from the central third to center the accompanying patellar bone plug at the superior pole of the patella. This has been shown to reduce the risk of iatrogenic patellar fracture [58].

Patella

The patella and patellar tendon are the final insertion points of all of the quadriceps muscles (see Fig. 1.4). The patella is the largest sesamoid bone in the body and has a complex trilaminar structure that is created by the insertion of the tendons from the quadriceps muscle complex. The osseous architecture is triangular in shape with 75 % of the deep surface of the patella articulating with the femur during knee motion. The articulating surface is composed of multiple facets named for their shape and position. The smaller medial and larger lateral facets are divided by a vertical ridge, while a further medial odd facet is also described in the literature [59]. The articular cartilage on the patella is the thickest articular cartilage in the body, averaging a depth of 5–6 mm [60, 61]. The different facets of the patella articulate with the trochlea of the distal femur by varying amounts as the degree of knee flexion or extension changes. While in extension, the lateral patellar facet articulates with the shallower proximal portion of the trochlea, and when the knee is in flexion the medial patellar facet articulates with the deeper distal portion of the trochlea and trochlear groove [59]. In extreme knee flexion, greater than 135°, the medial odd facet articular surface is in contact with the femur [59]. Patellar instability tends to occur with the knee in extension where the bony restraint is limited [62].

Patellar Tendon and Retinaculum

The patellar tendon is composed mainly of fibers from the rectus femoris muscle and runs from the inferior pole of the patella to the tibial tubercle with an average length of 4–5 cm [60, 63]. The patellar tendon is wider at its superior pole (3 cm) than it is at its inferior pole (2 cm) with a described thickness of 5–6 mm in the anteroposterior direction [48, 60]. The blood supply to the patellar tendon arises from the vertical anastomotic vessels surrounding the patella. The vessels course through the tendon from anterior to posterior, with the middle portion of the tendon receiving less blood flow in the adult compared to children [60].

The patella is stabilized in its track by the patellar tendon as well as the patellar retinaculum. Disruption of these supporting structures can lead to patellofemoral joint instability and anterior knee pain. The tendinous fibers from the vastus medialis and lateralis give rise to the medial and lateral patellar retinaculum on either side of the patella [60]. These fibrous sheets extend from the medial and fibular collateral ligaments to the edges of the patella and provide stability throughout flexion and extension [60]. The medial retinaculum plays a more important role in patellar stability and more specifically the medial patellofemoral ligament (MPFL), the primary restraint to lateral dislocation of the patella. The MPFL arises from the patella at the junction of the proximal one-third and distal two-thirds and inserts at the medial femoral epicondyle proximal to the MCL [64]. These support structures along with the forces exerted on the patella by the vastus medialis and lateralis muscles work to stabilize the patellofemoral joint through knee motion.

Biomechanics

The extensor mechanism of the knee consists of multiple muscles, tendons, and ligaments working together in unison to control knee extension. The extensor muscle complex plays an integral role during the swing phase of the gait cycle [65]. The rectus femoris contracts eccentrically in an effort to prevent over flexion of the knee in the early swing phase and works in concert with contraction of the hamstring muscles. Given its unique characteristic as the only knee extensor to also cross the hip joint, the rectus femoris also contributes to the flexion of the hip during the swing phase. During the late swing phase the quadriceps complex functions to extend the knee to within 10–20° of full extension. In this position the stride length is maximized and forward propulsion of the body is at its peak [65, 66]. As stride length increases, so too does the ground reaction force [66]. Increases in ground reaction forces lead to increased force transmission across the joints of the lower extremity and may play a role in injury patterns [32].

Imaging

Injuries to the hamstring and quadriceps muscle complexes are largely diagnosed with sound clinical acumen. The role of imaging modalities is largely confirmatory and in some cases prognostic in nature. Although this will be discussed in greater detail later in this text, briefly we will review the imaging algorithm. Plain radiographs should be obtained as the initial imaging modality to evaluate the osseous morphology, rule out fracture, and evaluate any avulsion injuries. Ultrasound may be used as a secondary tool to evaluate partial or complete tears of the patellar and quadriceps tendons. Ultrasound may also be employed in the evaluation of quadriceps and hamstring contusions.

Magnetic resonance imaging (MRI) has been shown to play an important role in the exclusion of proximal hamstring tears, which have a much better prognosis when surgically repaired in the early post-injury phase (Fig. 1.6) [2, 26]. The origins of the hamstring muscles are less easily visualized with ultrasound due to the overlying adipose and multifascicular gluteus maximus muscle [15, 26]. MRI can be helpful in determining the diagnosis and prognosis of hamstring muscle strains or quadriceps contusions in athletes, with typical findings that include high-signal intensity edema and hemorrhage located either at the main myotendinous junction, at the intramuscular portion of the tendon, or at the myofascial junction [27, 29, 67]. MRI may also be employed to serially follow healing soft tissue injuries and has been found to be more sensitive than ultrasound in this regard (Fig. 1.7) [10].

MRI and ultrasound have also been shown to be useful tools in the diagnosis of both

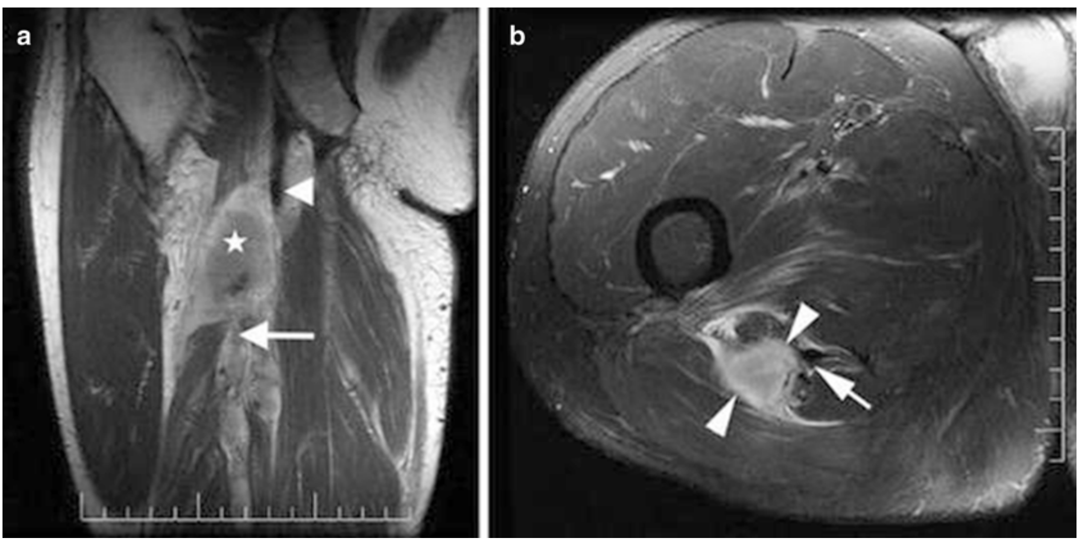

Fig. 1.6 Coronal and axial fat-suppressed MRI of the thigh. The coronal MRI (**a**) depicts an avulsion of the biceps femoris and semitendinosus muscles with a large hematoma (*star*) and the retracted fibers of the long head of the biceps (*arrows*). The axial MRI (**b**) shows a hematoma (arrow heads) and the disrupted semitendinosus musculotendinous junction (*arrow*). With kind permission from Springer Science+Business Media: Muscle Injury and Complications, 2010, Abhijit Datir

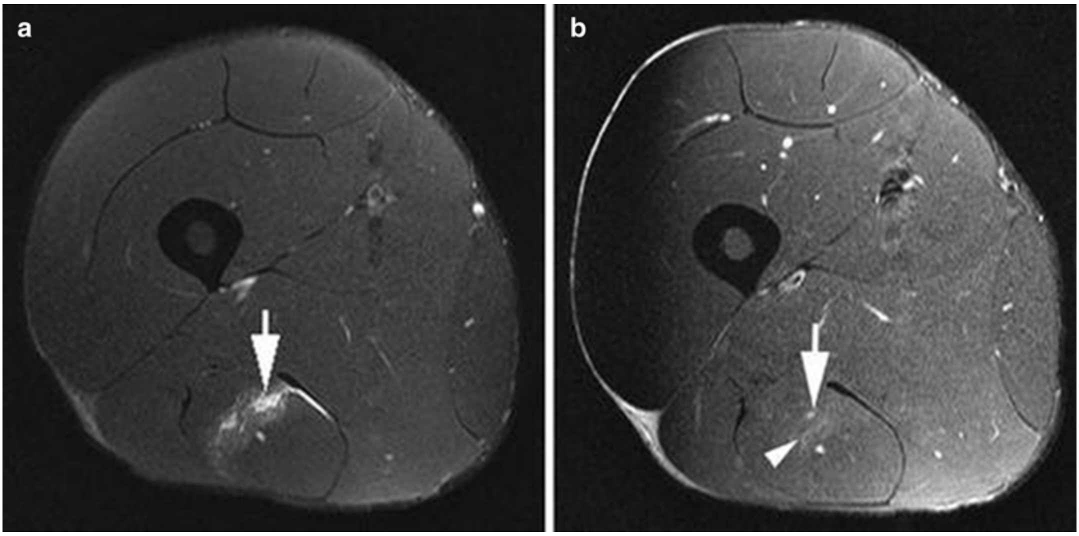

Fig. 1.7 Axial MRI of the thigh. The axial MRI (**a**) demonstrates a low-grade epimysial strain with edema and blood–fluid products at the onset of a semitendinosus strain (*arrow*). The axial MRI (**b**) at 4 weeks follow-up reveals a reduction in edema, blood–fluid products, and signal intensity (*arrow*). There is also the beginning of granulation tissue formation that appears as an intermediate signal (*arrowhead*). With kind permission from Springer Science+Business Media: Muscle Injury and Complications, 2010, Abhijit Datir

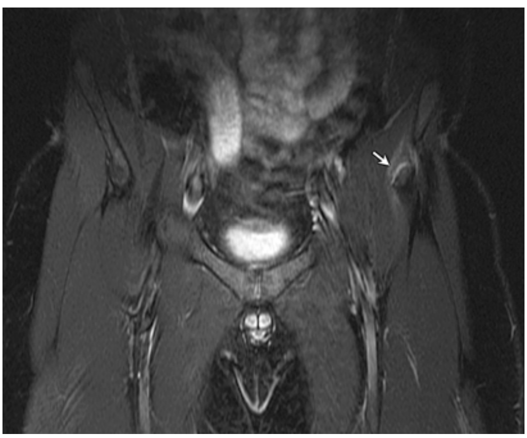

Fig. 1.8 Coronal T2-weighted fat-suppressed MRI of the pelvis. The proximal origin of the rectus femoris at the anterior inferior iliac spine (AIIS) is also susceptible to an avulsion injury in young athletes. This can be detected on coronal T2-weighted fat-suppressed imaging with high-intensity signal at the AIIS at the point of the rectus femoris origin (*arrow*). With kind permission from Springer Science+Business Media: Adult Hip Imaging for the Arthroscopist, 2013, Roy E. Erb

quadriceps and patellar tendon pathology, when the clinical picture is ambiguous. MRI imaging can be useful in distinguishing between complete and partial tears of the quadriceps tendon as well as proximal rectus femoris tendon avulsion (Fig. 1.8) [68]. Complete tears show no intact fibers, with the patella deviated anteriorly and a distinct wavy appearance of the tendon fibers [69]. In a partial tear, the tendon demonstrates a high-intensity signal within the midsubstance of the tendon, with some intact fibers passing around or through the injured area [53]. In patients presenting with quadriceps contusions, MRI can be used to rule out a space occupying hematoma (Fig. 1.9) [53]. Knowledge of the basic anatomy of the hamstring and quadriceps muscles along with accurate history, physical examination, and imaging are all important in making the correct diagnosis and prescribing the correct treatment for these injuries.

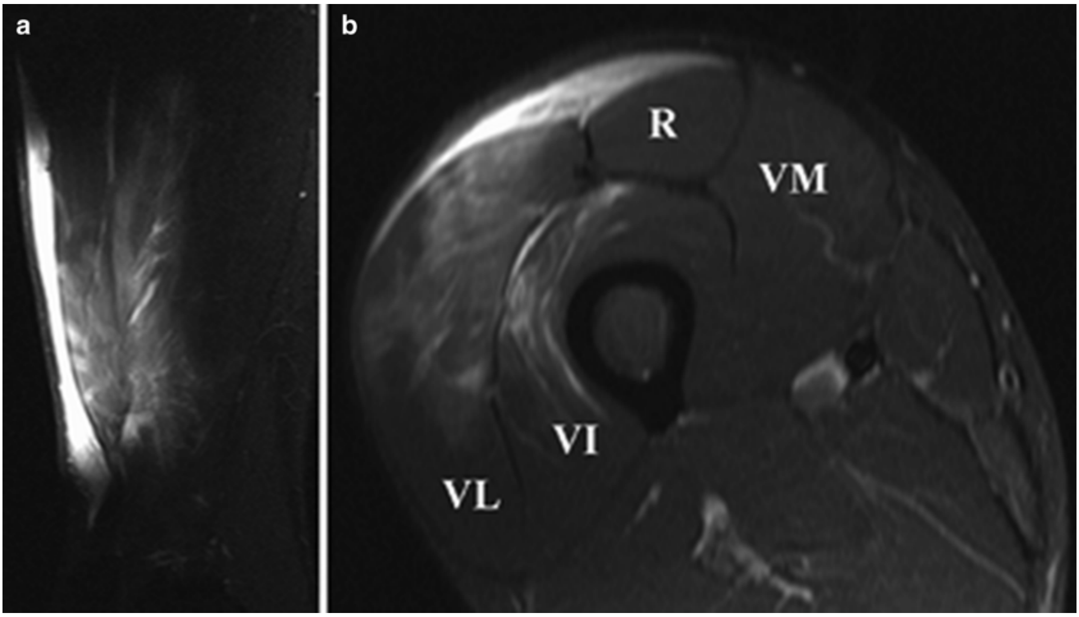

Fig. 1.9 Sagittal and axial STIR sequence MRI of the thigh. The anatomical position of the quadriceps muscle complex on the anterior thigh puts athletes in contact sports at risk for quadriceps contusions, which can be detected on MRI. Sagittal (**a**) and axial (**b**) imaging demonstrates a diffuse intramuscular hyperintensity, with epifascial hematoma in the rectus femoris (R), vastus lateralis (VL), and vastus intermedius (VI) muscles. VM, vastus medialis. With kind permission from Springer Science+Business Media: Insights into Imaging, Traumatic injuries of thigh and calf muscles in athletes: role and clinical relevance of MR imaging and ultrasound, 2012, Daichi Hayashi

Summary

The hamstring and quadriceps muscle groups are among the most commonly injured muscles in the active patient and a complete understanding of the anatomy is important for any physician treating this patient population. The purpose of this chapter was to outline the anatomy of the anterior and posterior thigh musculature. The structure, function, and biomechanics of the three muscles of the hamstring and four muscles of the quadriceps were outlined. Knowledge of the normal anatomy, clinically pertinent anatomic variants, and the most common pathologic conditions were presented so that the pathophysiology and treatment of these injuries can be discussed in greater detail in later chapters.

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2 Quadriceps and Hamstrings Strength in Athletes

Nienke W. Willigenburg, Michael P. McNally, and Timothy E. Hewett

Introduction

Adequate quadriceps and hamstrings strength are essential for athletic performance. These two muscles are functional antagonists; contraction of the quadriceps results in knee extension, while contraction of the hamstrings results in flexion of the knee joint. Together these muscle groups control accelerations and decelerations of the shank with respect to the thigh, and sufficient strength in both muscle groups is required for running, jumping, landing, and other athletic activities. But how do we measure strength? How much strength is required? And what happens when strength deficiencies are present? In this chapter, we will first discuss a commonly used method to assess quadriceps and hamstrings strength, as well as some frequently reported outcome measures. Then we will present a set of normative data for a variety of subject populations that we tested in our Biodynamics Laboratory of the Sports Health and Performance Institute at The Ohio State University (OSU). We will zoom in on a population of OSU football players to show how quadriceps and hamstrings strength relate to other functional and clinical tests. Finally, we will discuss how quadriceps and hamstrings strength may be associated with increased risk of lower extremity injury in athletes.

Assessment of Quadriceps and Hamstrings Strength in Athletes

Quadriceps and hamstrings strength in athletes can be reliably assessed using isokinetic dynamometry [1]. Isokinetic strength testing can be performed to test concentric or eccentric muscle strength at fixed angular velocities. Isometric muscle strength can be assessed at zero angular velocity with the upper and lower leg fixed in a static angle. The recorded strength is a measure of the net effect of the force developed by the quadriceps and hamstrings muscles to move the lower leg into extension and flexion. The net effect of these forces exerted around the knee joint can be recorded over a substantial range of motion (often 90°) at fixed speeds (often 60°/s and/or 300°/s). At low speeds (i.e., 0–180°/s), peak force reflects pure muscle strength, while neuromuscular control comes into play at higher speeds (>180°/s).

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Fig. 2.1 Setup for isokinetic testing of quadriceps and hamstrings strength

Testing at higher speeds better reflects muscle function during athletic activities than testing at lower speeds [2]. Concentric exertions are often preferred over eccentric exertions for feasibility and safety reasons. However, maximal eccentric exertions may provide important additional insight in muscle function, for instance as eccentric contraction occurs in the quadriceps during landing.

The set-up of isokinetic strength testing is important for optimal, reproducible results. When testing knee strength, the knee joint is aligned with the axis of the rotating arm and the pad for the rotating arm is secured just above the malleolus of the ankle joint. Straps around the chest, waist, and thigh are tightened to limit bodily motion other than knee flexion and extension (Fig. 2.1). During the test, the subject is instructed to kick out and pull back, as hard and as fast as possible, against the resistance of the machine, which moves at the predefined speed. It is recommended to record multiple repetitions within each test, as well as multiple trials with sufficient rest in between to improve data quality. Verbal encouragement is also recommended, as it enhances performance on maximal strength tests. Given the direction of gravity, the weight of the lower limb will "assist" the hamstrings and "counteract" the quadriceps muscles during upright seated isokinetic strength testing. Therefore, quadriceps and hamstrings peak torque should be corrected for the weight of the tested limb [3].

When assessing quadriceps and hamstrings strength in athletes, several outcome measures may be of interest. The most common measure of strength garnered from an isokinetic dynamometer is peak torque, a measure of the peak muscle force exerted during the test. Given the significant correlation between body weight and muscle strength [4–6], peak torque is often normalized to body weight. However, this normalization has been argued to overcorrect the effect of mass [6], and alternative normalization methods have been suggested [7]. Using non-normalized data can result in a high variability when comparing subjects with a wide range of body sizes, but should be appropriate for within-subjects comparisons, for instance to track an individual's knee strength over time.

In addition to peak torque values, ratios of peak torque are often calculated. These ratios provide important information about the relative strength of different muscle groups, or muscle imbalances, and thereby facilitate comparisons between subjects without the need for normalization. One such measure is the hamstrings-to-quadriceps ratio (H/Q ratio), calculated as the peak torque of the hamstrings divided by the peak torque of the quadriceps within the same limb (Eq. (2.1)):

$$H/Q\ \text{ratio} = \frac{\text{Hamstrings peak torque}}{\text{Quadriceps peak torque}} \qquad (2.1)$$

As stated before, isokinetic peak torque is often assessed using concentric contractions. As hamstrings and quadriceps muscles are antagonists to one another, simultaneous concentric contraction of both these muscles does not occur. Therefore, it may be preferred to examine eccentric hamstrings peak torque with respect to the concentric quadriceps peak torque, when assessing functional strength. This combination of eccentric hamstrings and concentric quadriceps strength is representative for the take-off phase of a jump: the quadriceps muscles contract and the shortening muscle fibers extend the knee, while a simultaneous eccentric (lengthening) contraction of the hamstrings is required to decelerate the explosive knee extension, in order to prevent hyperextension and resulting damage to the knee joint. A reduced H/Q ratio, which may be indicative of "quadriceps dominance," may put athletes at a higher risk for lower extremity injury [8].

Another ratio is calculated to compare peak torque between limbs and is referred to as the limb symmetry index (LSI). LSI is used to assess peak torque in the non-dominant relative to the dominant limb (Eq. (2.2)):

$$\text{LSI} = \frac{\text{Peak torque in non-dominant limb}}{\text{Peak torque in dominant limb}} \times 100\ \% \qquad (2.2)$$

Greater than 15 % difference between limbs is often considered a substantial asymmetry in healthy athletes and may put them at increased risk of injury [8]. Interestingly, such asymmetries are not uncommon in first-year professional American football players [6]. In injured subjects, LSI of the injured versus the unaffected limb can help to guide rehabilitation programs aimed at restoring symmetry between involved and uninvolved sides. LSIs of an injured population also provides further information when deciding whether athletes are ready to return to sport after recovering from an injury. An LSI of >90 % in injured athletes is typically recommended as a cutoff point when making return to sport decisions [9, 10]. Patients with this level of symmetry after rehabilitation following surgical reconstruction of their anterior cruciate ligament (ACL) demonstrated similar functional performance as healthy control subjects, while larger asymmetries were associated with reduced functional outcomes [11].

In addition to peak torque values and ratios of peak torque between muscle groups and limbs, several other outcome measures can provide further insight into muscle function. Table 2.1 provides an overview of some commonly used variables [12]. Additional electrical stimulation of the muscles or nerves during maximal voluntary contractions can reveal the discrepancy between voluntary and "true" maximal muscle strength.

Normative Data

When evaluating strength, normative values provide a range of normal strength values for a population that can be used to compare collected data. Tables 2.2, 2.3, 2.4, and 2.5 provide means and standard deviations of quadriceps and hamstrings strength measures for active individuals with and without ACL injuries, athletes who return to sport following surgical ACL reconstruction, and NCAA Division I football athletes. Reported normative values are peak torque and H/Q ratios at 60°/s and 300°/s.

As can be appreciated in these tables, peak torque for both quadriceps and hamstrings was lower when tested at a higher speed, while H/Q ratios tended to be higher when tested at a higher

Table 2.1 Relevant outcome measures based on isokinetic strength testing [12]

Outcome measure	Interpretation
Time to peak torque	Time from the start of a muscular contraction to the moment of peak torque development; indicative of the ability to produce force quickly
Angle of peak torque	The point in the range of motion where peak torque is produced; typically in the midrange, where the length–tension relationship of the muscle is optimal
Total work	Muscular force output over the entire test. This may be a better indicator of muscle function, as torque must be maintained over the range of motion
Work fatigue	Difference between the first 1/3 and the last 1/3 of work in a test bout; indicative of fatigue development throughout the test
Average power	Total work divided by time; represents how quickly a muscle can generate force
Coefficient of variance	Reproducibility of the test based on the amount of variation between repetitions. Acceptance levels are typically ≤15 % for larger muscle groups and ≤20 % for smaller muscle groups

Table 2.2 Isokinetic quadriceps and hamstrings strength measures at 60°/s for healthy subjects

		Healthy active females ($n=8$)	Healthy active males ($n=6$)	Freshmen varsity football ($n=22$)
Age		18.4 ± 4.6	23.7 ± 11.2	18.0 ± 0.7
HQ-ratio	Dominant	0.50 ± 0.05	0.55 ± 0.07	0.55 ± 0.07
	Non-dominant	0.49 ± 0.04	0.48 ± 0.08	0.52 ± 0.11
Peak torque (*Nm*)				
Quadriceps	Dominant	155.1 ± 19.7	233.2 ± 54.6	280.2 ± 54.8
	Non-dominant	153.6 ± 25.8	244.6 ± 50.2	277.0 ± 45.5
Hamstrings	Dominant	76.9 ± 8.9	127.8 ± 30.0	151.5 ± 28.6
	Non-dominant	74.7 ± 9.7	118.3 ± 38.9	142.7 ± 28.8
Peak torque normalized to body mass (*Nm*/*kg*)				
Quadriceps	Dominant	2.38 ± 0.17	2.47 ± 0.45	2.77 ± 0.46
	Non-dominant	2.37 ± 0.43	2.61 ± 0.56	2.75 ± 0.43
Hamstrings	Dominant	1.19 ± 0.15	1.36 ± 0.31	1.49 ± 0.23
	Non-dominant	1.15 ± 0.14	1.24 ± 0.27	1.41 ± 0.26

Table 2.3 Isokinetic quadriceps and hamstrings strength measures at 300°/s for healthy subjects

		Healthy active females ($n=8$)	Healthy active males ($n=6$)	Freshmen varsity football ($n=38$)
Age		18.4 ± 4.6	23.7 ± 11.2	18.0 ± 0.6
HQ-ratio	Dominant	0.67 ± 0.05	0.63 ± 0.07	0.67 ± 0.10
	Non-dominant	0.65 ± 0.08	0.68 ± 0.08	0.67 ± 0.11
Peak torque (*Nm*)				
Quadriceps	Dominant	81.6 ± 8.2	146.7 ± 27.8	178.9 ± 30.9
	Non-dominant	83.6 ± 7.5	137.9 ± 34.3	178.7 ± 37.7
Hamstrings	Dominant	54.0 ± 3.2	92.2 ± 20.2	118.0 ± 22.1
	Non-dominant	54.3 ± 7.9	92.9 ± 20.2	117.6 ± 21.6
Peak torque normalized to body mass (*Nm*/*kg*)				
Quadriceps	Dominant	1.25 ± 0.09	1.57 ± 0.34	1.76 ± 0.34
	Non-dominant	1.29 ± 0.18	1.49 ± 0.49	1.75 ± 0.37
Hamstrings	Dominant	0.83 ± 0.08	0.98 ± 0.22	1.17 ± 0.30
	Non-dominant	0.83 ± 0.09	1.00 ± 0.25	1.16 ± 0.28

Table 2.4 Isokinetic quadriceps and hamstrings strength measures at 60°/s for subjects who suffered an ACL injury

		Before surgical reconstruction		Cleared to return to sport after surgical reconstruction	
		Females ($n=10$)	Males ($n=20$)	Females ($n=13$)	Males ($n=22$)
Age		21.6 ± 10.0	22.7 ± 8.9	17.7 ± 5.5	21.8 ± 7.4
HQ-ratio	Uninvolved	0.55 ± 0.12	0.49 ± 0.07	0.48 ± 0.07	0.51 ± 0.07
	Involved	0.56 ± 0.10	0.49 ± 0.13	0.50 ± 0.08	0.48 ± 0.10
Peak torque (*Nm*)					
Quadriceps	Uninvolved	140.8 ± 42.5	214.0 ± 31.8	153.5 ± 27.1	233.7 ± 50.1
	Involved	94.1 ± 43.0	159.0 ± 39.8	127.8 ± 18.9	213.7 ± 48.6
Hamstrings	Uninvolved	76.0 ± 24.8	105.3 ± 20.7	73.9 ± 13.7	117.6 ± 26.1
	Involved	51.0 ± 21.0	75.9 ± 23.0	63.3 ± 14.1	100.0 ± 22.8
Peak torque normalized to body mass (*Nm/kg*)					
Quadriceps	Uninvolved	2.13 ± 0.68	2.63 ± 0.57	2.40 ± 0.41	2.77 ± 0.47
	Involved	1.49 ± 0.83	1.95 ± 0.57	2.02 ± 0.38	2.53 ± 0.50
Hamstrings	Uninvolved	1.16 ± 0.45	1.30 ± 0.32	1.15 ± 0.16	1.40 ± 0.30
	Involved	0.80 ± 0.41	0.92 ± 0.29	1.00 ± 0.24	1.19 ± 0.24

It is important to note that the populations of subjects before and after surgical reconstruction only partly overlap (female: $n=4$, male: $n=10$)

Table 2.5 Isokinetic quadriceps and hamstrings strength measures at 300°/s for subjects who suffered an ACL injury

		Before surgical reconstruction		Cleared to return to sport after surgical reconstruction	
		Females ($n=10$)	Males ($n=20$)	Females ($n=13$)	Males ($n=22$)
Age		21.6 ± 10.0	22.7 ± 8.9	17.7 ± 5.5	21.8 ± 7.4
HQ-ratio	Uninvolved	0.70 ± 0.12	0.67 ± 0.10	0.65 ± 0.08	0.65 ± 0.10
	Involved	0.76 ± 0.06	0.69 ± 0.13	0.67 ± 0.09	0.68 ± 0.17
Peak torque (*Nm*)					
Quadriceps	Uninvolved	81.6 ± 21.3	122.2 ± 20.9	84.5 ± 13.4	139.6 ± 24.2
	Involved	62.6 ± 24.9	100.6 ± 21.1	77.7 ± 9.3	131.3 ± 25.8
Hamstrings	Uninvolved	56.4 ± 17.0	80.7 ± 13.5	56.4 ± 7.9	90.3 ± 19.4
	Involved	48.2 ± 18.6	68.1 ± 12.9	53.7 ± 8.0	87.5 ± 21.7
Peak torque normalized to body mass (*Nm/kg*)					
Quadriceps	Uninvolved	1.24 ± 0.39	1.50 ± 0.33	1.32 ± 0.15	1.66 ± 0.27
	Involved	0.97 ± 0.47	1.23 ± 0.31	1.22 ± 0.18	1.57 ± 0.34
Hamstrings	Uninvolved	0.87 ± 0.34	0.99 ± 0.23	0.87 ± 0.07	1.07 ± 0.17
	Involved	0.73 ± 0.36	0.84 ± 0.18	0.83 ± 0.09	1.05 ± 0.29

It is important to note that the populations of subjects before and after surgical reconstruction only partly overlap (female: $n=4$, male: $n=10$)

speed. This supports previous findings in an extensive review [13], and may be explained by the increased forward momentum of the tibia at higher angular velocities, which requires increased co-activation of the hamstrings muscles to prevent anterior translation of the tibia and hyperextension of the knee joint [14]. While some subjects showed substantial side-to-side asymmetries, the LSI is small when averaged over a group of healthy athletes. As LSIs higher or lower than 100 % are both commonly observed, a group average tends to mask the range of individual asymmetries.

Before surgical reconstruction, ACL-injured subjects show substantially reduced quadriceps and hamstrings peak torques in their involved leg, while H/Q ratios are similar between legs (see Tables 2.4 and 2.5). Rehabilitation after ACL reconstruction is aimed at resolution of side-to-side asymmetries, and indeed the strength deficiencies in the involved limb are reduced in subjects who are cleared to return to sports.

Isokinetic Strength and Function in NCAA Division I Football Athletes

At The Ohio State University, all incoming freshmen of the college football team participate in an extensive preseason athletic screening. Isokinetic knee strength is just one of the multiple clinical, biomechanical, and functional testing stations in this athletic screening. In addition, all subjects complete an injury history questionnaire and detailed injury reports are collected over the course of the football season. This extensive database is growing each year and is used to evaluate differences between position groups, between performances on different clinical and functional tests and, eventually, for prospective analyses to identify risk factors for injury.

The following paragraphs discuss the relationships between isokinetic knee strength and three different functional screening tests, all measured in the dominant limb. First, we will describe how knee strength relates to performance on the Functional Movement Screen™ FMS™ which will emphasize the effect of normalizing strength data to body mass. Then we discuss knee strength in relation to a set of clinical hop tests, and in relation to isometric hip strength. The last portion of this section will describe the association between measures of limb asymmetry based on knee strength, hop tests, and hip strength.

Quadriceps and Hamstrings Strength vs. Functional Movement Screen™

The FMS™ was introduced as an approach to predict athletic performance [15]. The FMS™ consists of seven fundamental movement tasks, scored on a scale from 0 to 3 based on task execution (i.e., mobility, stability, and compensatory movements), with the aim to pinpoint deficient areas of mobility and stability that may be overlooked in an asymptomatic active population [16]. While performance on the FMS™ combines multiple aspects of athletic function (strength, balance, stability, mobility), one could hypothesize that football players with higher quadriceps and hamstrings strength could perform better on the FMS™.

Pearson's correlation coefficients were calculated between non-normalized peak torques and FMS™ scores and a negative association was observed between performance on the FMS™ and quadriceps strength tested at 300°/s, while no significant correlation was observed between FMS™ scores and hamstrings strength or quadriceps strength tested at a lower speed (Fig. 2.2). This indicates that football players with greater quadriceps strength at high speeds perform worse on the FMS™. However, when we normalized the knee strength data to body mass, this significant correlation was not observed (Fig. 2.3). Apparently, heavier players exhibited greater knee strength, and obtained lower scores on the FMS™. Indeed, a significant correlation between FMS™ scores and body mass index ($r=-0.41$, $p=0.01$) was observed in this data set. These results support previous findings that lower FMS™ scores are associated with a higher body mass index [17], rather than with stronger quadriceps muscles. This example illustrates how the choice whether or not to normalize quadriceps and hamstrings strength data can substantially affect clinical findings.

Quadriceps and Hamstrings Strength vs. Clinical Hop Tests

Hop tests are clinical measures commonly used to assess athletic performance and side-to-side asymmetries in a simple and dynamic manner. Our football players performed a set of four single-leg hop tests: a single hop for distance, a triple crossover hop for distance, a triple hop for distance, and a 6 m timed hop (Fig. 2.4).

Performance on the triple hop for distance was significantly correlated with all body mass-normalized isokinetic peak torque values except for hamstrings strength tested at a low speed (Fig. 2.5). This indicates that athletes with

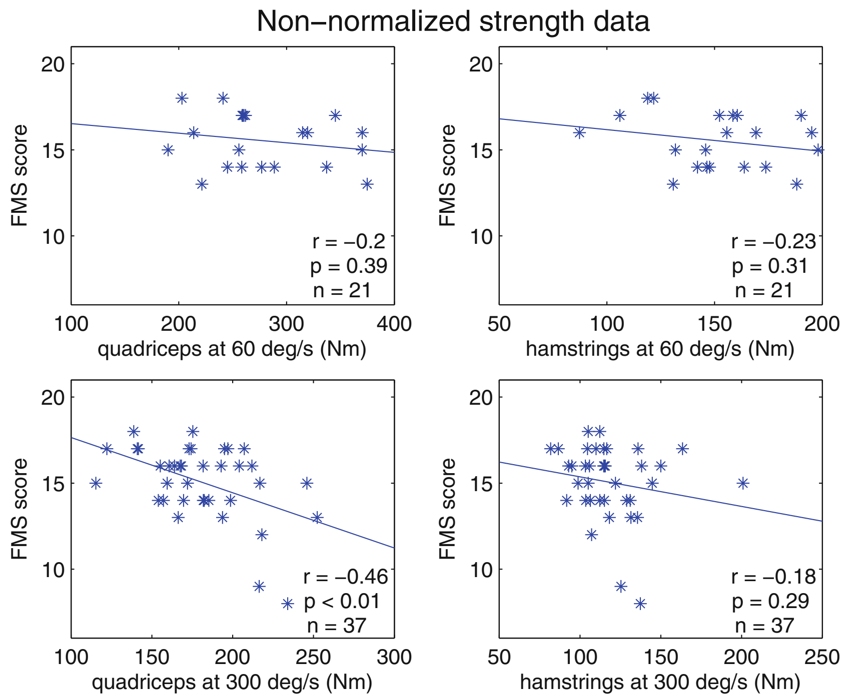

Fig. 2.2 Correlations between non-normalized knee strength and FMS scores

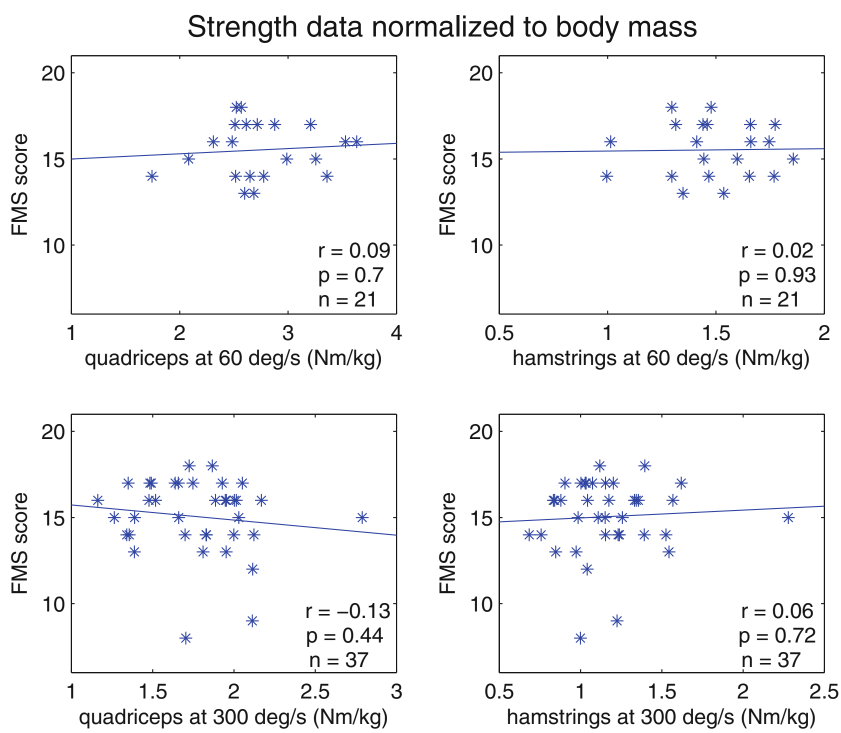

Fig. 2.3 The significant correlation between quadriceps strength at 300°/s and FMS score is no longer observed after normalization of peak torque to body mass

stronger thigh muscles landed their third hop further than athletes with weaker thigh muscles (normalized to body mass). Interestingly, the strongest correlations were observed for both quadriceps and hamstrings peak torque measured at 300°/s. This supports previous findings that testing at a higher speed better reflects dynamic athletic performance [2]. The relationship between quadriceps strength and triple hop distance may be most intuitive, given the quadriceps' function of extending the knee joint for a powerful take-off. However, the biarticular hamstrings muscles originate on the pelvis and insert on the tibia and fibula, and thus span both the knee joint, where they act as flexors, and the hip joint, where they act as extensors. Stronger hamstrings can therefore improve hop performance by generating large hip extension moments during take-off and by stabilizing the knee during landing.

Table 2.6 shows the correlations between isokinetic peak torque and all hop tests. The lack of significant correlation between single hop distance and knee strength may be due to the limited amount of data. The crossover hop requires substantial coordination and balance skills as it involves frontal plane displacement in addition to sagittal plane movements. This may explain the lack of significant correlation between quadriceps and hamstrings peak torque and performance on the crossover hop for distance.

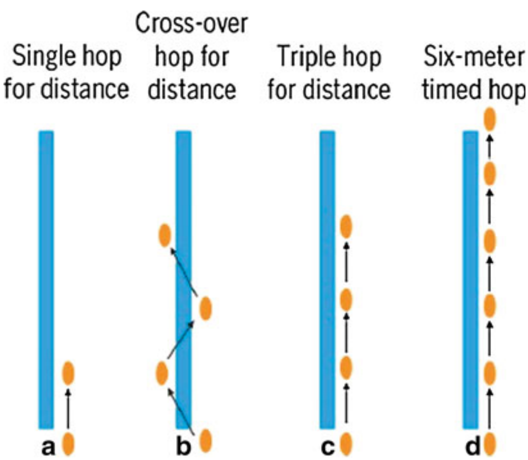

Fig. 2.4 Hop tests

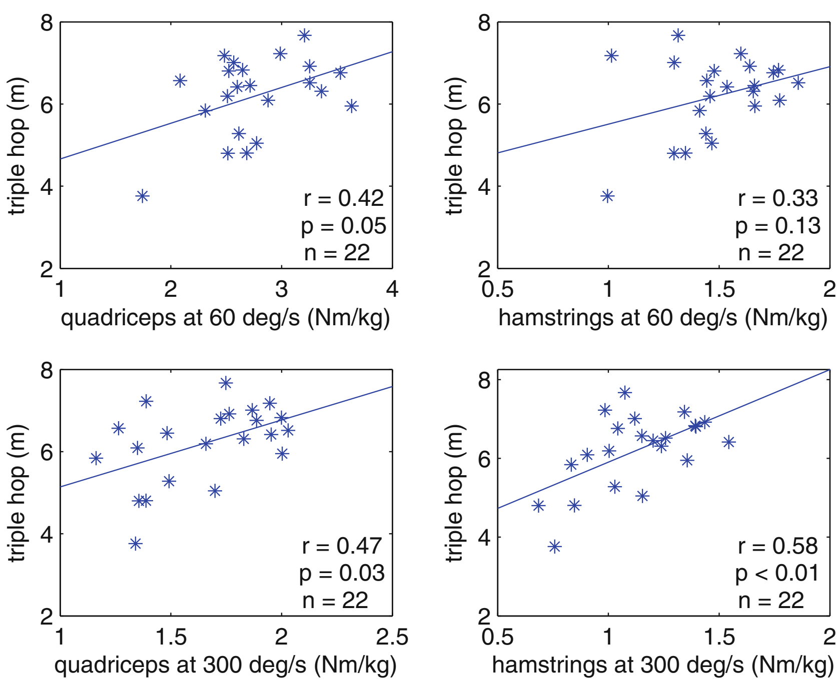

Fig. 2.5 Performance on the triple hop for distance is positively correlated with most isokinetic knee strength measures

Table 2.6 All correlations between isokinetic quadriceps and hamstrings strength and hop test performance

Peak torque normalized to body mass	Single hop			Triple hop			Crossover hop			6 m timed hop		
	r	*p*	*n*	*r*	*p*	*n*	*r*	*p*	*n*	*r*	*p*	*n*
Quad_60°/s	ND	ND	ND	**0.42**	**0.05**	**22**	0.31	0.16	22	**–0.45**	**0.04**	22
Quad_300°/s	0.00	0.99	11	**0.47**	**0.03**	**22**	0.21	0.23	33	0.01	0.98	32
Ham_60°/s	ND	ND	ND	0.33	0.13	22	0.26	0.25	22	–0.38	0.08	22
Ham_300°/s	0.22	0.52	11	**0.58**	**<0.01**	**22**	0.30	0.10	33	–0.25	0.16	32

Note that difference between positive and negative correlation coefficients between the normalized and non-normalized peak torque
ND no data
Values in bold represent significant effects

Quadriceps and Hamstrings Strength vs. Hip Abduction Strength

The contribution of the hip musculature is often overlooked when assessing knee strength and control. The muscles surrounding the hip joint play a significant role in controlling the position of the femur during dynamic tasks [18]. The following section presents hip strength data collected using a custom load cell device. The load cell, placed between two straps surrounding the distal portions of the thighs, recorded maximal force while the thighs were abducted and externally rotated in both side-lying and standing postures (Fig. 2.6). The following knee isokinetic and hip isometric strength data are normalized to body mass.

Less than half of the correlations between isokinetic knee strength and isometric hip strength were significant (Table 2.7). In other words, athletes with strong (or weak) quadriceps or hamstrings do not necessarily have strong (or weak) hip muscles as well. The standing isometric hip abduction test showed the strongest association with isokinetic knee strength, with significant correlations ranging from 0.39 to 0.52 for all peak torque measures except quadriceps strength tested at 60°/s (Fig. 2.7). The hamstrings peak torque at 300°/s showed the strongest association with isometric hip strength, with significant correlation coefficients ranging from 0.43 to 0.52 for all hip strength measures except the standing external rotation test. The finding that hip and knee

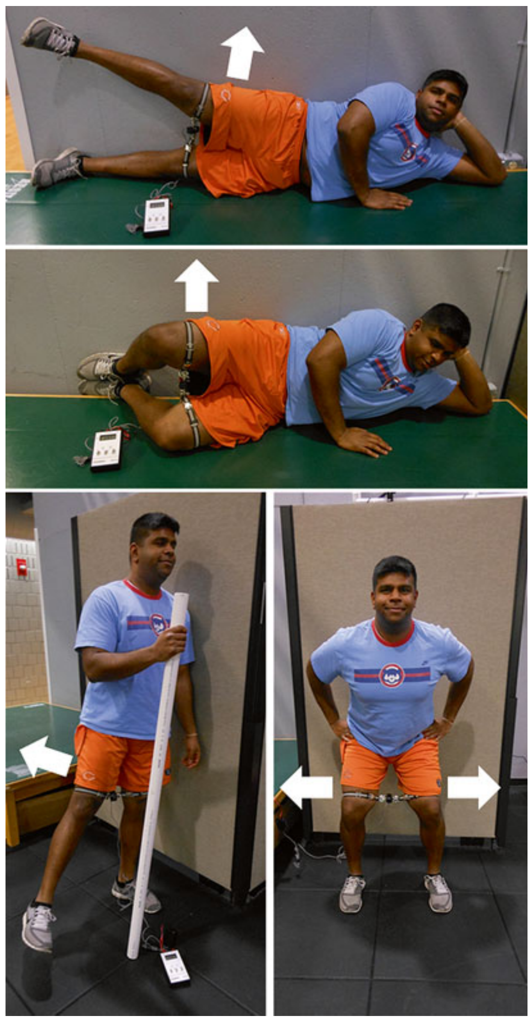

Fig. 2.6 Isometric hip abduction and external rotation strength test

Table 2.7 Correlations between isokinetic quadriceps and hamstrings strength and isometric hip strength

Peak torque normalized to body mass	Side-lying hip abduction			Side-lying hip external rotation			Standing hip abduction			Standing hip external rotation		
	r	*p*	*n*	*r*	*p*	*n*	*r*	*p*	*n*	*r*	*p*	*n*
Quad_60°/s	0.35	0.11	22	0.29	0.18	22	0.29	0.19	22	0.41	0.06	22
Quad_300°/s	**0.37**	**0.04**	**31**	**0.41**	**0.02**	**32**	**0.39**	**0.03**	**32**	**0.36**	**0.03**	**35**
Ham_60°/s	0.36	0.10	22	0.32	0.14	22	**0.46**	**0.03**	**22**	**0.42**	**0.05**	**22**
Ham_300°/s	**0.51**	**<0.01**	**31**	**0.43**	**0.01**	**32**	**0.52**	**<0.01**	**32**	0.24	0.17	35

All strength measures are normalized to body weight
Values in bold represent significant effects

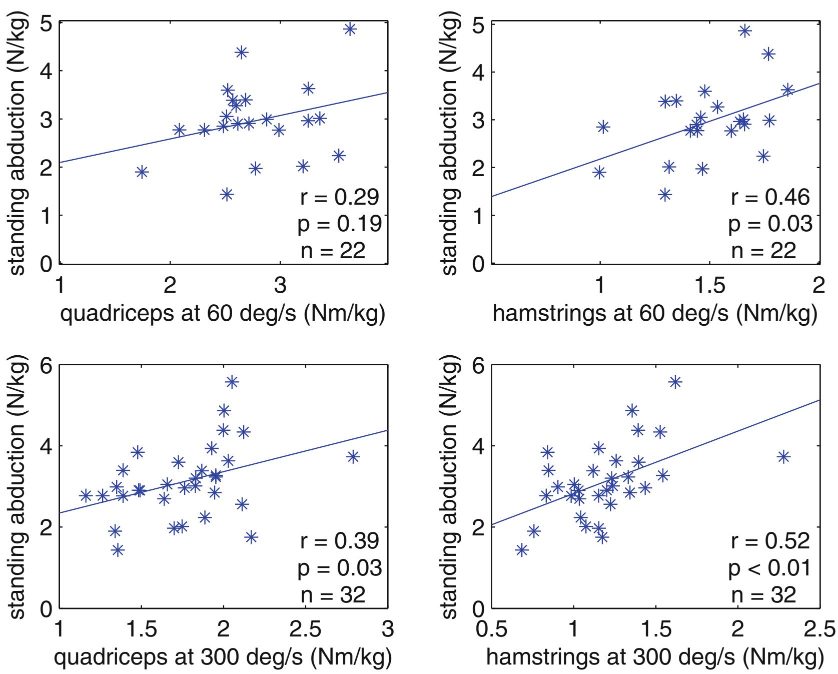

Fig. 2.7 Mostly positive, but moderate correlations between hip and knee strength. Both strength measures are normalized to body mass

strength are only partially and moderately correlated indicates that improvement of hip and knee strength requires function-specific training of each muscle group.

Limb (A)symmetry

Asymmetries between limbs in strength and function may affect athletic performance. Moreover, limb asymmetry is a risk factor for lower extremity injury [8]. The LSI (Eq. (3.2)) quantifies the difference between limbs. In other words, it indicates how good (or bad) performance with the non-dominant (or injured) limb is with respect to the dominant (or unaffected) limb. LSIs can be calculated for each single-leg task that is performed on both legs. In this section, we discuss how the LSIs that were calculated based on the previously described tests (i.e., isokinetic hamstrings and quadriceps strength, functional hop tests, and isometric hip strength) relate to each other in our population of freshmen collegiate football athletes.

LSI for quadriceps strength was significantly correlated to LSI for hamstrings strength, both at 60°/s ($r=0.48$, $p=0.02$, $n=22$) and at 300°/s ($r=0.46$, $p<0.01$, $n=38$). This indicates that the

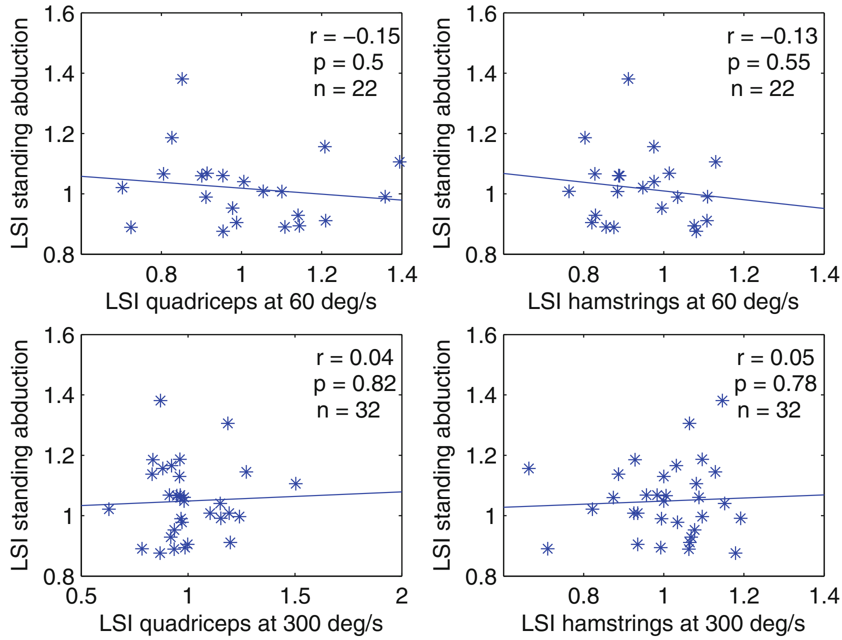

Fig. 2.8 Limb asymmetry based on knee strength measures does not correlate with limb asymmetry based on hip strength measures

asymmetry between limbs is (at least partly) consistent between knee flexors and extensors. Another significant correlation was observed between LSI for quadriceps strength tested at the higher and the lower speed ($r=0.65$, $p<0.01$, $n=22$). This indicates that subjects with quadriceps asymmetry at the low speed also tended to show quadriceps asymmetry at the high speed (although the absolute values of the LSI may differ between speeds). Interestingly, no such correlation was observed for the hamstrings muscles ($r=0.30$, $p=0.17$, $n=22$), which indicates that LSIs based on hamstrings strength were inconsistent between speeds of testing. Fast hamstring contractions are less common in most sports than explosive quadriceps contractions, therefore, athletes may have difficulty with rapid hamstring activation during the test at the high speed.

While asymmetries in knee strength seem to be related, this does not necessarily indicate that similar asymmetries will be seen within the hip musculature (Fig. 2.8). No significant correlations were observed between LSI based on knee strength and LSI based on hip strength. Similarly, no significant correlations were observed between LSIs calculated from isokinetic knee strength measures and LSIs calculated from any of the functional hop tests. These results indicate that strength asymmetries in the quadriceps and hamstrings muscles do not directly translate to functional asymmetries in athletic tasks. Therefore, these separate assessments of limb asymmetry cannot substitute one another, and they provide insight in different aspects of discrepancies between limbs.

Deficiencies in Quadriceps and Hamstrings Strength as a Risk for Injury

Several studies have associated deficiencies in quadriceps and hamstrings strength with increased risk for lower extremity injuries [8, 19–22]. However, other studies reported no significant association between strength deficiencies and injury risk [23–25]. These inconsistent findings likely result from the variety of research protocols (i.e., speed of isokinetic testing, concentric or eccentric contractions), outcome measures (i.e., peak torque, HQ-ratio, asymmetry measures), research populations (i.e., male vs.

female athletes and different sports), and reported injuries (i.e., injuries in general, all lower extremity injuries, specific injuries such as hamstrings strains or ACL ruptures) in these studies.

Hamstrings Strain-Type Injuries

Four recent reviews [26–29] discuss the risk factors for hamstrings strain, concluding that current evidence for isokinetic strength measures as predictors of hamstrings injuries is inconsistent. Freckleton and Pizzari [27] performed several meta-analyses of prospective studies investigating the role of isokinetic knee strength as a risk factor for hamstrings injury. They calculated the standardized mean difference (SMD) and its 95 % confidence interval (CI) by dividing the injured and non-injured group means by the pooled standard deviation (SD), thus providing a measure of the difference between players who went on to suffer a hamstrings injury and those who remained injury free. No difference between injured and uninjured athletes was observed in concentric H/Q ratio at 60°/s (SDM = –0.50, 95 % CI = –1.17 to 0.18, $p=0.15$, based on five studies and 216 subjects). Another meta-analysis did not support concentric hamstrings peak torque as a risk factor for hamstrings strain (SMD = –0.24, 95 % CI = –0.85 to 0.37, $p=0.44$, based on 4 studies and 195 participants). However, a meta-analysis of these same studies showed that a high quadriceps peak torque was a significant risk factor for hamstrings muscle strain-type injuries (SMD = 0.43, 95 % CI = 0.05–0.81, $p=0.03$). Next to age and previous hamstrings injury, quadriceps peak torque was the only strength based factor consistently associated with hamstrings strain-type injuries [27].

In a more recent study, Zvijac and colleagues [6] collected isokinetic quadriceps and hamstrings strength at the National Football League (NFL) Scouting Combine, and all 32 NFL teams identified players who suffered hamstring injuries during their first season ($n=203$, of which 164 had usable strength data). In contrast to previous reports, neither quadriceps nor hamstrings strength was predictive of hamstrings injury in first-year professional football players. None of the knee strength measures (quadriceps and hamstrings peak torque, H/Q ratio, and side-to-side asymmetry) were different between injured and uninjured limbs, or between injured and uninjured control players [23].

One of the largest prospective studies not only tested preseason isokinetic strength (both concentric and eccentric) in professional soccer players, but also included an intervention to resolve any existing strength imbalances [19]. Athletes in the intervention group participated in a hamstrings conditioning program, consisting of manual, isotonic or isokinetic strengthening, and a subset of players underwent subsequent isokinetic testing until the strength imbalance was resolved. Out of 462 players who completed the study, 35 hamstrings injuries were reported. Soccer players were considered to have preseason "strength imbalances" if they showed significant deficiencies in at least two out of seven parameters that reflected side-to-side hamstring strength asymmetries and H/Q ratios at different speeds and modes of testing. The frequency of hamstrings injury during the season was lowest (4.1 %) in soccer players with no preseason strength imbalance, while the injury frequency was highest in players with untreated strength imbalances (16.5 %). The group who participated in the hamstrings conditioning program with repeated follow-up isokinetic tests to verify the efficacy of the intervention, had an injury frequency of 5.7 %, not statistically different from that in the group without preseason strength imbalances. In the athletes who participated in the intervention without repeated follow-up isokinetic tests, the frequency of hamstrings injuries remained elevated (11 %). These results indicate that the incorporation of a combination of strength imbalances may be more valuable than a single parameter when assessing risk of hamstrings injury, and that adequate training may help to reduce injury risk by normalizing these imbalances.

Anterior Cruciate Ligament (ACL) Injuries

One of the primary functions of the ACL is to restrain anterior translation of the tibia with respect to the femur. Activation of the hamstrings muscles supports the ACL in this function. In vitro, strain on the ACL was substantially reduced with simultaneous activation of hamstrings and quadriceps muscles, compared to activation of the quadriceps muscles alone [30, 31]. These and other findings [32–34] imply that deficiencies in hamstrings strength may increase the risk of ACL injury.

Söderman and colleagues [22] studied risk factors for lower extremity injuries in 146 female soccer players, with five of these athletes ultimately suffering an ACL injury. A lower H/Q ratio was a significant predictor for traumatic injuries of the lower extremity in general. While this number of ACL injuries was too small for accurate statistical analyses, all of the ACL-injured soccer players showed preseason concentric H/Q ratios <0.55 in the injured limb, which was lower than the H/Q ratio in the uninjured side [22]. Myer and colleagues (2009) studied risk factors for ACL injury in female soccer and basketball players. The 22 athletes who sustained ACL injuries showed a combination of decreased hamstrings strength, but similar quadriceps strength when compared to male athletes. In contrast, female athletes who did not suffer ACL injuries showed decreased quadriceps strength, but similar hamstrings strength compared to male controls. While no significant differences between injured and uninjured female athletes were observed, these findings indicate that "quadriceps dominance" may be a risk factor for ACL injury [21]. Moreover, a recent study showed that insufficient hamstrings strength compromised landing technique in adolescent girls, resulting in high-risk biomechanical movement patterns [35]. Without providing direct statistical evidence, the results of these studies tend to support the theory that deficiencies in hamstrings strength may increase the risk for ACL injury. And indeed, our neuromuscular training program aimed at prevention of ACL injuries has been successful in both improving hamstring strength [36] and reducing ACL injury risk [37].

Summary

Quadriceps and hamstrings strength are usually quantified by the peak torque during maximal voluntary isokinetic contractions. Ratios of peak torque are used to assess limb asymmetry and hamstrings strength relative to quadriceps strength. Peak torque is affected by the mode and speed of testing, and whether or not to normalize peak torque (e.g., to body mass) is an important consideration. Positive, but moderate correlations were observed between knee strength and triple hop distance and between knee strength and hip strength in a population of collegiate freshmen football players. No significant correlation was observed between knee strength and FMS™ performance, or between limb symmetry indices based on different strength and functional tests. Deficiencies in quadriceps and hamstrings strength may increase the risk of lower extremity injuries, but large prospective studies are needed to determine which measures of strength are the best predictors for specific injuries and to optimize injury prevention strategies.

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3 Epidemiology of Hamstring and Quadriceps Injury

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Hamstring Injury

Hamstring strains and ruptures comprise a very large percentage of musculoskeletal injuries during activities and sporting events amongst all age groups of athletes and levels of competition. Athletes involved in soccer, football, rugby, and track are particularly prone to this injury due to the explosive nature of movement in these sports and the demand to sprint at maximal efforts. Dancers and water skiers are classically also afflicted with this condition because of stretch on the hamstring musculature. Additionally, there has been research evaluating this injury in cross-country skiing, downhill skiing, judo, cricket, and bull riding. There is a relatively large amount of literature that describes the epidemiologic data concerning this injury. Most of the epidemiologic studies have looked at individual leagues such as the Union of European Football Associations (UEFA) or the National Football League (NFL), or groups of athletes such as rugby players, track athletes, or dancers. The following is a summary of the current relevant literature on the epidemiology of hamstring injuries.

There are several well-done papers that look at professional soccer leagues or teams and the incidence of hamstring injuries. The UEFA injury study was a prospective cohort study that followed UEFA soccer clubs for seven consecutive seasons [1]. This study recorded individual player exposure and time-loss injuries from 2001 to 2008. There were a total of 4,483 injuries registered during matches and training, of which 525 were hamstring strains (12 %). They calculated that a team of 25 players can expect seven hamstring strains per season. The risk of sustaining a hamstring strain during the season was much higher than during preseason. Hamstring strain was the most common diagnosis of all injuries among these elite-level athletes. They concluded that the high intensity of the sport was the etiology of this fact.

In 2004, the British Journal of Sports Medicine reported on the incidence of hamstring injury in football clubs from professional English football leagues between 1997 and 1999 [2]. Their data showed that 12 % of all injuries suffered in those two seasons were hamstring injuries, with slightly over half of these being found in the biceps femoris. There was no significant difference between dominant and non-dominant extremity. Higher levels of competition suffered more hamstring injuries. Ninety-one percent of

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injuries occurred in a noncontact fashion, and 57 % occurred during running. Approximately one-third of injuries happened in training, and two-thirds occurred in matches. African American players suffered more injuries than Caucasians, and older players experienced more hamstring injuries compared to younger. The reinjury rate was found to be 12 %.

Another study evaluated the 1998–1999 soccer season in England and looked at the link between flexibility and hamstring strains in English professional football players [3]. They saw 1,435 injuries from 30 different clubs. Four hundred seventy-nine of those injuries were muscle strains, and 158 of those were hamstring injuries. This represented 11 % of all injuries and 33 % of all muscle injuries. Fourteen percent of hamstring injuries were reinjuries. Two-thirds of injuries happened during matches compared to training sessions. Two-thirds occurred later in activity compared to early in matches or practices. Almost all injuries were managed conservatively; only 1.9 % (3 of 158) were treated with surgery. They concluded that there was a relation between flexibility training protocols and hamstring strain rates in this player group.

Henderson et al. also looked at professional soccer players; this time in the English Premier League (EPL) [4]. Their paper reported very similar results to the above-mentioned study. They determined that odds for sustaining a hamstring strain increased 1.78 for each 1-year increase in age. There was a 1.47 odds increase for each 1-cm increase in non-counter movement jump test, and 1.29 for each 1-degree decrease in active range of hip flexion. Thus older, more powerful, and less flexible soccer players are at the greatest risk of sustaining a hamstring injury. This finding has been confirmed in multiple studies to date.

Intercollegiate soccer in America has been looked at through the NCAA Injury Surveillance System [5, 6]. A specific study from February 2013 compared the incidence of this injury in males to females throughout the 2004–2009 seasons [7]. This data showed that overall males were 64 % more likely (Incidence Rate Ratio [IRR] of 1.64) to suffer a hamstring strain than women. Men had significantly more hamstring strains in games and in practice settings. There was no significant difference between males and females when looking at the preseason. Males were significantly more likely to have an in-season strain with an IRR of 1.98. Men had a statistically significant higher chance of having a recurrence, 12–22 % ($p=0.003$). There was no difference between events or athlete characteristics when examining hamstring strain rates of males compared to males, and females compared to females.

The NFL has had several descriptive studies that have evaluated the epidemiology of hamstring injuries. One particular study looked at training camp injuries between 1998 and 2007 (Table 3.1) [8]. The most common injury that occurred was knee sprains, followed by hamstring strains and contusions of any body site. Hamstring strains were much more likely to occur in preseason games compared to practices (4.07 vs. 1.79 athlete injuries/1,000 exposures). This correlates to an injury rate ratio of 2.3 from games to practices. In practices there were approximately 2.2 injuries for every 1,000 athlete exposures. Each hamstring strain resulted in a loss of 8.3 days on average. Tight ends were the most prone to injury overall, but running backs, defensive backs/safeties, and wide receivers were the most prone to having a hamstring injury.

Elliott et al. examined hamstring strains among NFL football players in 2011 [9]. They retrospectively reviewed prospectively collected data from 1989 to 1998. Over 10 years, 1,716 hamstring strains occurred, an incidence of 0.77 injuries per 1,000 athletic exposures. Per year, this averaged out to 144 players sustaining 172 hamstring strain injuries. The rate of injury was noted to be much higher during preseason practices as opposed to in-season practice sessions; 47.3 % of all injuries occurred during games, though. Positions that are reliant on explosive speed, such as defensive backs and wide receivers, accounted for 43.9 % of all strains. Special teams players, notably punters, had a high incidence as well. This paper's findings determined that the average player missed

Table 3.1 Epidemiology of National Football League training camp injuries from 1998 to 2007[a]

Injury rates of specific injuries					
Injury	Total occurrences	AE/1,000 in practice	AE/1,000 in games	IRR[b]	95 % CI[c]
Knee sprain	120	2.12	10.84	5.1	4.8–5.4
Hamstring strain	85	1.79	4.07	2.3	2.1–2.5
Contusion	83	0.92	12.47	13.5	13.3–13.7
Ankle sprain	69	1.10	6.78	6.2	6.0–6.4
Lumbar strain	51	1.17	2.44	2.1	1.9–2.1
Shoulder sprain	52	0.80	5.42	6.8	6.2–7.2
Fracture/dislocate	50	0.67	6.23	9.3	9.1–9.5
Groin strain	34	0.70	1.63	2.3	2.1–2.5
Foot sprain	32	0.52	3.52	6.7	6.4–7.0
Cervical strain	29	0.60	1.36	2.3	2.1–2.5
Hip flexor strain	29	0.65	1.08	1.7	1.4–2.0
Quadriceps strain	28	0.60	1.08	1.8	1.5–2.1
Achilles strain	24	0.55	1.36	2.5	2.0–3.0
Concussion	19	0.17	3.25	18.6	17.8–19.4
Abdominal strain	10	0.17	0.81	4.7	4.3–5.1
Elbow sprain	10	0.10	1.63	16.3	16.0–16.6
Gluteal strain	5	0.12	0.00	0.0	0.0–0.9

AE athlete exposure, *IRR* injury rate ratio, *CI* confidence interval
[a]Feeley B, Kennelly S, Barnes R, Muller M, Kelly B, Rodeo S, Warren R. Am J Sport Med (36), 1597-1603, copyright ©2008 by SAGE Publications. Reprinted by Permission of SAGE Publications
[b]IRR comparing rate of injury in games to rate of injury in practices
[c]$P = 0.05$

13.2 days due to a single hamstring strain (median 9 days per injury).

Complete hamstring rupture is an uncommon event in the NFL [10]. This injury was reported via the NFL Injury Surveillance System ten times in the time period between 1990 and 2008. Mean age at the time of injury was 27.2 years old. All injuries occurred in the regular season, and 8/10 occurred after week 4. The breakdown by position was two defensive backs, two defensive linemen, two linebackers, one quarterback, one wide receiver, one running back, and one tight end. Six of ten players recalled hip hyperflexion coupled with knee extension. Other injured athletes recalled running and cutting. Three players recalled prodromal symptoms. This particular study attempted to determine how successful athletes were at returning to play after this event. Nine out of ten returned to play. The one player who did not return to play showed symmetric strength between legs, but subjectively reported diminished speed. Four players returned to play, but only played in one game. Interestingly, one player had a complete proximal hamstring rupture of the contralateral side shortly thereafter. Neither of the two undrafted players who had this injury returned to play more than one game.

In collegiate football, the most comprehensive study is from the Journal of Athletic Training in 2007 [11]. This paper reported on 16 years of epidemiologic data reported via the Injury Surveillance System. They stated that during the 16-year reporting period, 19 % of NCAA institutions sponsoring football participated in the Injury Surveillance System. There was little variation in overall injury rate over time. Regarding all injuries (not just hamstring strains), they noted 36 injuries per 1,000 athlete exposures (A-Es) during games. In fall practice, they noted approximately four injuries per 1,000 A-Es. In spring practice, they noted about ten injuries per 1,000 A-Es. When looking specifically at hamstring strains, data from this study was grouped as “muscle-tendon strain” of the upper leg, thus this could include quadriceps and hamstring strains both. Regardless, they reported data in three separate groups, which were fall games, fall practices, and spring practice. In the 16 years during fall games, there were 1,103 upper leg strains. This accounted for 3.6 % of all injuries. During games, the injury rate per 1,000 athlete exposures was 1.24. Fall practices showed 4,518 thigh strains, accounting for 10.7 % of practice injuries. The injury rate per 1,000 athlete exposures was found to be 0.41. And in spring there were far less upper leg strains, 1,179. Similar to fall practices, the percentage of injuries from this condition was 10.8 %. And the injury rate per 1,000 athlete exposures in the spring was 1.04.

Hamstring injuries in professional rugby players have received a particularly significant amount of attention in the past. This is due to the common nature of this injury in this particular population of athletes. In a paper out of the UK published on the Rugby Football Union they noted 16,782 h of match exposure and 196,409 h of training exposure which resulted in 164 hamstring strains (0.27 injuries/1,000 player hours) [12]. The incidence of injury in matches was 5.6 injuries per 1,000 player hours. In total this caused 2,707 days of absence from training or competition. Injuries were graded as minor, moderate, or major based on time missed from participating (≤1, 1–3, and ≥3 weeks, respectively). They found that 37 % were minor in nature, 37 % moderate, and 26 % were called severe. They noted that the incidence of hamstring injuries seemed to increase as matches reached the last quarter (minutes 61–80) of competition. Interestingly, substitute players showed a higher rate of injury at a level of 10.7 injuries per 1,000 h. The highest incidence of strains occurred during running activities, but more severe injuries were a result of kicking activities (average 36 days lost to training or matches). They evaluated demographics of participants and did not note any significant differences in the incidence of hamstring injuries as a function of age, height, body mass, or BMI. The incidence of injury among backs was four times higher in players of African or Caribbean descent as opposed to Caucasians.

Football injuries in Australia have been surveyed extensively as well. Verrall et al. suggested that 30 % of Australian football players in two clubs had posterior thigh pain over one season [13]. Orchard and Seward have long-term data on this unique epidemiology [14–16]. Amongst three leagues in the 1992 season, they reported 2,398 injuries in 57 teams. Hamstring strains were the most commonly reported injury in Australian Rules football (13 %) of all injuries recorded. Head and face lacerations were more common in rugby players (Rugby League and Rugby Union). Injuries tended to occur in the middle segments of matches, and more injuries happened at the beginning of the season compared to later months of the season. Of all hamstring strains, 34 % were recurrent injuries. Hamstring strains accounted for the most time missed from participation. In the discussion section of this particular paper they compared injuries in the Australian Football League (AFL) to a prior paper that described injury trends in the Victorian Football League during the 1983–1985 seasons. They noted that hamstrings strains have been increasing in incidence (8.9 % of injuries in past to 13.4 % in the 1992 season). Orchard and Seward again evaluated epidemiologic data in the AFL, this time from 1997 to 2000. This subsequent data again showed hamstring strains as the most common affliction of all injuries. About six hamstring strains occurred per season per club of 40 players. This represented 15 % of all injuries. Hamstring strains again showed the highest rate of recurrence of all injuries. There were approximately 3.7–4.3 strains per 1,000 player hours in matches. Most recently the group published their data again in the American Journal of Sports Medicine in April of 2013 (Table 3.2). They looked at their data from the AFL from 1992 to 2012. There were a total of 2,253 new hamstring injuries and 588 recurrent injuries, causing 7,322 matches to be missed. The average recurrence rate was 26 %. Each club missed an average of 20.4 matches per player per club season due to hamstring strain. They noted over the 21 years that players took longer to return to play after muscle injuries, and recurrence rates tended to

Table 3.2 Results of two decades of injury surveillance and public release of data in the Australian Football League[a]

Injury type by body area	Average, 1999–2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Average, 2003–2012
Head/neck												
Concussion	0.8	0.3	0.3	0.7	0.3	0.3	0.4	0.5	0.5	1.1	1.0	0.5
Facial fracture	0.6	0.6	0.8	0.6	0.3	0.4	0.2	0.5	0.5	0.5	0.6	0.5
Neck sprain	0.1	0.0	0.1	0.2	0.3	0.1	0.2	0.1	0.1	0.1	0.1	0.1
Other head/neck injury	0.1	0.3	0.2	0.1	0.2	0.2	0.1	0.1	0.2	0.2	0.2	0.2
Shoulder/arm/elbow												
Shoulder sprain and dislocation	0.8	1.3	1.0	1.4	1.6	1.0	1.8	1.3	1.6	1.8	1.3	1.4
Acromioclavicular joint injury	0.9	0.3	1.1	0.8	1.2	0.8	0.7	0.5	0.8	0.7	0.5	0.7
Fractured clavicle	0.3	0.2	0.6	0.3	0.3	0.3	0.1	0.2	0.2	0.1	0.2	0.3
Elbow sprain or joint injury	0.1	0.1	0.3	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.2
Other shoulder/arm/elbow injury	0.5	0.5	0.4	0.6	0.3	0.2	0.3	0.1	0.3	0.4	0.6	0.4
Forearm/wrist/hand												
Forearm/wrist/hand fracture	1.3	0.8	1.1	1.3	1.1	0.9	1.2	1.1	1.2	1.6	0.8	1.1
Other hand/wrist/forearm injury	0.4	0.7	0.4	0.3	0.3	0.6	0.4	0.4	0.3	0.4	0.5	0.4
Trunk/back												
Rib and chest wall injury	0.9	0.8	0.7	0.4	1.0	0.4	0.7	0.3	0.6	0.4	0.4	0.6
Lumbar and thoracic spine injury	1.5	0.8	1.6	2.1	1.5	1.3	1.5	1.4	1.7	1.4	1.5	1.5
Other buttock/back/trunk injury	0.8	0.5	0.6	0.4	0.6	0.5	0.7	0.5	0.4	0.6	0.9	0.6
Hip/groin/thigh												
Groin strain/osteitis pubis	3.2	2.9	3.1	2.9	3.3	4.0	3.2	3.3	4.1	2.8	2.6	3.2
Hamstring strain	6.0	5.7	6.3	5.2	6.4	6.7	6.6	7.1	6.0	4.8	5.7	6.0
Quadriceps strain	2.0	2.0	1.9	1.9	1.7	1.8	1.8	2.1	1.7	1.4	1.6	1.8
Thigh and hip hematoma	1.2	0.3	1.1	1.0	1.1	0.6	0.5	1.0	1.1	0.5	0.4	0.8
Other hip/groin/thigh injury, including hip joint	0.2	0.4	0.3	0.2	0.3	0.8	0.8	1.0	0.7	1.0	1.2	0.7
Knee												
ACL	0.9	0.6	0.5	0.6	0.9	0.6	0.9	0.7	0.6	0.9	0.8	0.7
MCL	1.1	1.0	0.7	1.0	0.8	1.4	1.3	0.7	0.8	1.0	0.9	0.9
PCL	0.5	0.5	0.7	0.4	0.3	0.2	0.3	0.3	0.4	0.6	0.3	0.4
Knee cartilage	1.4	1.7	1.2	1.3	1.0	1.2	1.6	2.0	1.7	1.5	1.0	1.4
Patella injury	0.3	0.1	0.1	0.3	0.3	0.3	0.2	0.2	0.5	0.4	0.2	0.3
Knee tendon injury	0.5	0.7	0.4	0.7	0.4	0.3	0.3	0.5	0.4	0.6	1.0	0.5
Other knee injury	0.9	0.7	0.7	0.9	0.2	0.8	1.0	1.0	0.4	0.8	0.8	0.7
Shin/ankle/foot												
Ankle joint sprain, including syndesmosis sprain	2.3	2.6	2.5	2.5	2.1	2.2	2.5	2.6	3.4	2.9	2.6	2.6
Calf strain	1.7	1.6	0.9	1.9	1.6	1.2	2.0	1.3	1.7	2.1	3.0	1.8
Achilles tendon injury	0.4	0.4	0.2	0.3	0.3	0.4	0.6	0.6	0.4	0.9	0.7	0.5

(continued)

Table 3.2 (continued)

Injury type by body area	Average, 1999–2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Average, 2003–2012
Leg and foot fracture	0.7	0.5	0.5	0.4	0.7	0.5	0.5	1.0	0.9	0.7	0.3	0.6
Leg and foot stress fracture	0.8	0.9	0.9	0.9	1.1	1.1	0.9	0.9	1.2	1.3	1.3	1.1
Other leg/foot/ankle injury	1.4	1.5	1.7	1.3	1.5	1.3	1.1	1.5	1.7	2.5	2.0	1.6
Medical illness	1.7	2.4	2.0	2.2	0.7	1.9	2.1	2.9	2.1	1.8	2.2	2.0
Non-football injury	0.2	0.4	0.1	0.1	0.2	0.2	0.3	0.2	0.5	0.1	0.5	0.3
New injuries per club per season	36.6	34.1	34.8	35.3	34.0	34.6	36.9	37.8	38.7	38.4	38.1	36.4

ACL anterior cruciate ligament, *MCL* medial collateral ligament, *PCL* posterior cruciate ligament
[a]Orchard J, Seward H, Orchard JJ. Am J Sports Med (41), 734-741, copyright © 2013 by SAGE Publications. Reprinted by Permission of SAGE Publications

decrease as time went on. However, severity of injury with regard to amount of matches missed tended to slightly increase over time.

Sprinters and track athletes have been evaluated in the literature for incidence of hamstring injuries. Most of this data comes from observational studies of single events, such as the Olympic Games. One of the best studies that assess this injury in track athletes looked at 3 years of epidemiologic data from the Penn Relays [17]. This meet is unique in that there are a very large number of athletes of all ranges of professionalism, age, gender, and event type. This paper defined a hamstring injury as acute onset of posterior thigh pain which made the athlete quit the competition. Over the 3 years, 48,473 athletes participated in the relays, and slightly more men than women competed. There were a total of 489 injuries documented. Hamstring injury was the most common condition that was recorded accounting for 24.1 % ($n=118$) of all injuries. Men showed a higher likelihood of suffering hamstring injury compared to women with an OR of 1.79. There were no hamstring injuries reported in junior high school athletes. Masters athletes were significantly more likely to sustain a hamstring injury compared to high school athletes with an OR of 4.26, and compared to college/elite-level athletes with an OR of 3.55. When looking at events, the 4×400 m relay showed the highest risk of suffering a hamstring injury. Interestingly, the risk in this event was higher than in the 4×100 m relay. There was no statistically significant difference in incidence between the 4×100 and 4×200 m relays. There were too few participants in the 100, 110 m hurdles, and the triple jump to reliably evaluate this data; however, they all showed relatively high rates of hamstring injury. In agreement with other studies, increasing age was a significant independent risk factor for injury. And, like other studies, male master athletes were more likely to suffer hamstring injury than their female master athlete counterparts [18].

In 1996 a retrospective cohort study out of Australia evaluated 95 track athletes over a 12-month period [19]. Seventy-two athletes suffered 130 injuries with an injury rate of 3.9/1,000 training hours. Hamstring strains accounted for 14 % of all injuries, and were the second most common diagnosis behind stress fractures. As expected this injury was more common among sprinters, hurdlers, jumpers, and multi-event athletes.

A study of Grecian track and field athletes from 2010 attempted to predict recovery time after hamstring injury based on knee range of motion [20]. Their inclusion criteria found 165 participants. Of the various events, sprinters accounted for 75 of the 165 (45 %), long and triple jumpers 39 (24 %), combined events 23

Table 3.3 Mean values for factors potentially associated with the occurrence of acute hamstring injuries in dancers[a]

	Acutely injured			Uninjured		
Variables	Women	Men	All	Women	Men	All
Dancers (*n*)	27	6	33	33	15	48
Age (years)	22	22	22	21	22	21
Body mass (kg)	58.4	68.0	63.2	56.0	70.3	60.5
Body height (m)	1.66	1.77	1.68	1.66	1.79	1.70
BMI (kg/m^2)	21.1	21.6	21.4	20.3	21.9	21.6
Previous dance (*n*, years)[b]	27 (6.0)	6 (4.3)	33 (5.7)	33 (6.4)	15 (4.3)	48 (5.8)
Previous athletic training (*n*, years)[b]	19 (6.7)	4 (4.5)	23 (6.3)	19 (4.8)	11 (7.1)	30 (5.6)
Present extracurr. dance training (*n*, hours)[c]	14 (3.9)	2 (4.0)	16 (3.9)	20 (4.3)	8 (4.9)	28 (4.5)

[a]Reprinted from Askling C, Lund H, Saartok T, Thorstensson A. Self-reported hamstring injuries in student dancers. Scand J Med Sci Sports 2002; 12: 230–235. Copyright © 2002, John Wiley and Sons
[b]>2 times/week before starting at the Ballet Academy
[c]>2 h/week in addition to training at the Ballet Academy

(14 %), throwers 15 (9 %), and middle and long distance runners 13 (8 %). Another study by the same group out of Greece looked into the rate of recurrence of hamstring strain injuries [21]. This study showed that the average time to return to sport after initial injury was 7.4 days for grade I injuries, 12.9 days for grade II injuries, 29.5 days for grade III injuries, and 55.0 days for grade IV injuries. Twenty-three of the original 165 subjects had a recurrent injury (13.9 %). 9.3 % of grade I injuries recurred, and 24.1 % of grade II injuries recurred. Higher grade injuries were much less likely to occur, but were fewer in number. Grade III injuries happened again at a rate of 7.7 %. Surprisingly, none of the grade IV injuries recurred.

Epidemiologic data concerning upper and lower extremity injuries in active military personnel has been extensively looked at in the past. Despite a plethora of studies, surveillance systems, and data, the incidence of hamstring injuries in this population has not been commented on often. Often the literature reports data as strain of the upper leg or of the leg in general, so determining the incidence of hamstring strain or rupture is ambiguous. One closely related study to this issue was published by Hartig and Henderson [22]. They investigated the rate of lower extremity injuries between a group of trainees undergoing a dedicated hamstring flexibility program and a control group. They found that static hamstring stretching three times daily significantly decreased the rate of lower extremity injuries, although they did not examine hamstring strain or rupture in particular in this unique group of athletes. Another study looked at 1,296 Marine recruits reviewed during 12 weeks of athletic training during boot camp [23]. 39.6 % of recruits suffered an injury during this process, and 82 % of those injuries were to the lower extremities. There were a total of 13 recruits who sought medical attention for hamstring strain. They reported the incidence of hamstring strain as 1.1 %.

Another subset of athletes that classically have been plagued with hamstring injuries is dancers. Askling et al. have written several excellent papers on this linkage [24–27]. In one epidemiologic study they sent a questionnaire to dancers at the Ballet Academy in Stockholm (Table 3.3). This retrospectively collected data had 98 participants and showed that 34 % of the athletes reported an acute hamstring injury. Seventeen percent recalled a chronic injury to their posterior thigh. Unique to dancers, most of the injuries (88 %) occurred during slow activities related to flexibility training. The other 12 % occurred during power movements, much like other sports such as soccer, football, or rugby. Dancers tended to ignore their injury, and tried to continue participation in their sport despite pain. Only 4 % (4 of the 98) ever sought medical attention for their hamstring injury.

The last subset of patients who are classically linked to hamstring strains and tears is water skiers. This connection is so established that it is frequently a favorite vignette on in-training and written board examinations. Romano et al. were the first to document this relationship [28]. The epidemiologic data concerning hamstring injuries in water skiers is scant. Most of the literature is case studies of small quantities of patients. One of the larger cohorts collected was published in the American Journal of Sports Medicine in 1996 out of Duke University [29]. They had a subset of 12 patients. There were eight men and four women. Half of the patients afflicted were elite or high level skiers. Half were beginning skiers or patients who had never skied before. Injuries were split evenly between the left lower extremity and the right lower extremity. Another study in the American Journal of Sports Medicine used data from the National Electronic Injury Surveillance System to look at water-skiing and wakeboard-related injuries between 2001 and 2003 [30]. In these 3 years, there were 2,044 water-skiing injuries to the upper leg, which accounted for 25.7 % of all comers. There were 130 wakeboarding injuries to the upper leg, which accounted for 10.5 % of all wakeboarding injuries. The most common injury to water skiers was strains and sprains of the lower extremity. The most common injury for wakeboarders was laceration. Men represented the vast majority of injuries in both groups. Experts tended to hurt themselves by falling, and beginners tended to hurt themselves when attempting to get to an upright position.

Quadriceps Injury

Much like the literature on hamstring injury, the literature on quadriceps injury is fairly detailed, however not quite as prevalent and in depth. Data has been presented on the incidence and rate of quadriceps strain, quadriceps tendon rupture, and quadriceps contusion among athletes. These specific problems will be examined in closer detail to delineate the epidemiologic data available.

Similar to hamstring injuries, quadriceps injuries among professional soccer players have been inspected. Ekstrand et al. evaluated three male cohorts from the UEFA Champions League, the Swedish First League, and an artificial turf cohort [31]. They pooled this data and there were a total of 2,299 players followed over nine seasons. Their goal was to evaluate this group of professional soccer players for all muscle injuries. They evaluated 998,000 h of training exposure and 177,000 h of match play exposure. Two thousand nine hundred eight muscle injuries were identified. Of this amount, 19 % occurred in the quadriceps. This trailed only the hamstrings and the adductors in occurrence (37 % and 23 % of all injuries, respectively). The majority of quadriceps strain affected the dominant kicking leg in 60 % of cases, the non-dominant leg in 33 %, and both legs in 7 % of cases. Almost all injuries to the quadriceps occurred in noncontact situations (96 % of the time). Quadriceps strains were significantly more likely to occur towards the end of each half. Muscle injuries in general increased with increasing age, and were much more common in match play compared to training. Quadriceps strains caused statistically significant more time missed from competition than hamstring did (17 days compared to 14 days).

This same group then looked in even further detail at risk factors for quadriceps injury in UEFA soccer players (Table 3.4) [32]. There were 394 quadriceps injuries in 1,401 players in this particular study. Again, quadriceps injuries were more common in the dominant leg (63 % of the time). Goalkeepers had a significantly decreased rate of injury to their quads compared to defenders, midfielders, and forwards.

Table 3.4 Significant risk factors for lower extremity muscle injury from multiple Cox regression and logistical regression analysis[a]

Injury	Variable	HR/OR[b]	95 % CI	*P* value
Adductors				
	Player-related factors			
	Previous adductor injury	1.40	1.00–1.96	0.047
	Goalkeeper[c]	0.51	0.29–0.91	0.022
	Match-related factors			
	Away match[d]	0.56	0.43–0.73	<0.01
Hamstrings				
	Player-related factors			
	Previous hamstring injury	1.40	1.12–1.75	0.003
	Goalkeeper[c]	0.11	0.06–0.24	<0.001
	Match-related factors			
	Away match[d]	0.76	0.63–0.92	0.004
	Fall period (September–November)[e]	2.16	1.29–3.60	0.003
	Winter period (December–February)[e]	2.55	1.53–4.24	<0.001
	Spring period (March–May)[e]	2.49	1.49–4.17	<0.001
Quadriceps				
	Player-related factors			
	Previous quadriceps injury	3.10	2.21–4.36	<0.001
	Previous adductor injury	1.68	1.16–2.41	0.006
	Previous calf injury	1.91	1.24–2.93	0.003
	Goalkeeper[c]	0.41	0.20–0.82	0.012
	Match-related factors			
	UEFA Champions League match[f]	0.48	0.24–0.97	0.040
Calf				
	Player-related factors			
	Previous calf injury	2.33	1.52–3.57	<0.001
	Previous adductor injury	1.71	1.15–2.55	0.008
	Previous hamstring injury	1.74	1.24–2.44	0.002
	Goalkeeper[c]	0.36	0.16–0.82	0.015
	Older player (age above mean)	1.93	1.38–2.71	<0.001
	Match-related factors			
	UEFA Champions League match[f]	2.72	1.78–4.14	<0.001

CI confidence interval, *HR* hazard rate, *OR* odds ratio, *UEFA* Union of European Football Associations. *Previous injury* refers to injury during the preceding season

[a]Hagglund M, Walden M, Ekstrand J. Am J Sports Med (41), 327-335, copyright © 2013 by SAGE Publications. Reprinted by Permission of SAGE Publications

[b]HRs are given for player-related factors from Cox regression analysis (adjusted for match exposure ratio; match exposure/total exposure); ORs are given for match-related factors from logistic regression analysis

[c]Reference group for playing position: forward

[d]Reference group for match venue: home match

[e]Reference group for period of season: preseason (July–August)

[f]Reference group for match type: league match

Interestingly, previous injury to the quadriceps, adductors, or calf muscles increased the rate of quadriceps injury. The hazard ratio of having a previous quad injury and sustaining another one was 3.10. There did not appear to be any match-related factor (i.e., home vs. away, part of the season, climate) which affected the rate of quadriceps injury, but playing in the UEFA Champions League appeared to decrease the rate of quadriceps injury for some reason. This study failed to show a relationship between age of the player and rate of quadriceps injury.

A prospective study looked at 249 male professional soccer players in Belgium before the 1999–2000 season [33]. One hundred three players were excluded from the study because of a history of prior muscle injury. The remaining players had their flexibility formally examined before the season. Of the 146 players, 13 (8.9 %) had a quadriceps injury during the season. Consistent with other studies and theories, the players who had less flexible quadriceps musculature were more susceptible to quadriceps strain. But, this effect was less pronounced than with hamstrings flexibility and strains.

Less information is known about the incidence of quadriceps injury in female soccer players. One of the few studies available appears to be a study of Norwegian elite female soccer players which attempted to determine risk factors for lower extremity injuries [34]. This paper looked at 12 teams, 173 players, during the 2009 season. One hundred seventy-one injuries were recorded. Thirty-two injuries affected the thigh, and 80 % of these involved the hamstring. That left seven players who had a quadriceps condition. Unlike the previous study, prior history of hamstring injury did not have an influence on experiencing a new thigh injury. Demographic, neuromuscular, and anatomic factors were not associated with new injury, but BMI was found to increase the risk of thigh injury by 51 % per standard deviation increase.

Detailed information on quadriceps injury in adolescents is lacking. There are many injury surveillance studies in youth and high schoolers that describe injuries in general terms such as "strain," "thigh strain," or "thigh contusion," but few studies have been performed that look specifically at quadriceps strain or hamstring strain. One study that mentioned quadriceps strain in youths looked at a soccer camp for boys and girls between the ages of 6 and 17 years old [35]. Data was collected prospectively during a week-long camp in Northwest Washington state. Overall they evaluated 681 boys and 458 girls. The camp involved 22 h of soccer participation in training exercises and competitive events. The authors observed 216 soccer-related injuries amongst the 1,139 participants. Girls suffered 107 injuries (10.6/1,000 h) and boys 109 injuries (7.3/1,000 h). While only one hamstring injury was noted in both genders, quadriceps strain was the most frequently documented injury overall in males (12 of 109 injuries, 11.0 %). There were six quadriceps strains in females (6 of 107 injuries, 5.6 %). The majority of quadriceps strains were found in the right leg.

Data from NFL training camps between 1998 and 2007 showed that quadriceps injury was quite common [8]. Quadriceps strain occurred 28 times among the 696 different players documented. This corresponded to a total of 0.60 strains per 1,000 athlete exposures in practices, and 1.08/1,000 athlete exposures in games. The injury rate ratio was 1.8 when comparing rate of injury in games to rate of injury in practices. The average player lost 5.4 days after suffering this injury. This particular paper also reported on contusions, but did not look at quadriceps contusion alone. Rather, it included contusion of any body location.

Distal quadriceps tendon rupture in NFL athletes has been examined by the Steadman-Hawkins group out of Denver [36]. They retrospectively looked at injuries from 1994 to 2004 and identified 14 unilateral quadriceps tendon rupture injuries. Ten of the 14 patients suffered the injury through an eccentric contraction of the extensor mechanism. Eleven patients had a complete rupture, whereas three had a partial rupture. Only one player had antecedent quadriceps symptoms. A variety of positions suffered the injury, but defensive tackles and ends seemed to be more likely to have the injury than other positions (7/14). No anabolic steroid use was reported. The group noted that those players who returned to play showed a trend towards an earlier draft status compared to those who did not return to play. Age and pre-injury experience did not significantly influence player outcome after repair.

In the NFL, avulsion of the rectus femoris has also been reported [37]. In 2009 a paper reported the results of a review of the NFL Injury Surveillance System from 1986 to 2006. Eleven total cases were identified starting in 1997. Thus, this injury was noted to occur about once per year in the entire league. The injury occurred in games seven times, and in practice four times. The injury was not seen in kickers/punters alone, but rather in a variety of positions on both offense and defense. The full return to play in games took 69.2 days on average.

Similar to the epidemiologic data of hamstring injuries, there is a prevalent amount of literature on quadriceps injury in rugby and Australian rules football. A study out of the British Journal of Sports Medicine examined injuries in the Rugby World Cup of 2011 [38]. This evaluated a population of 615 international rugby players representing 20 teams who competed in New Zealand that year. The paper examined basic player demographics and reported injury rates per player match hours. They only noted two anterior thigh muscle injuries that both occurred in training. The two injuries necessitated 24 days of absence from rugby activities. This is in stark contrast to posterior thigh muscle injuries, which occurred 20 times and accounted for 523 days of absence from competition. The authors collected data from the 2011 season, and compared it to a prior study they had done in 2007 [39], and there were no statistically significant changes in overall risk and nature of injuries.

Orchard and Seward et al. also tracked quadriceps strain epidemiology over the years as they followed football in Australia. In their index study in 1993 they reported 2,398 injuries in 57 teams in three separate leagues. Quadriceps strains accounted for 5.6 % of injuries in the AFL, 1.4 % in the Rugby League, and 0.9 % in the Rugby Union. In their study of injuries from 1997 to 2000, they noted the incidence of quadriceps strain was 2.5 per club of 40 players per season. The recurrence rate of the four years surveyed was 23 %. This correlated to 1.1 match injuries per 1,000 player hours in AFL matches. The rate in non-match activity was also 1.1/1,000 player hours, and they noted 0.5 preseason injuries per club per season. Per seasons, clubs missed 7.6 matches due to this injury.

In Orchard and Seward's 20-year surveillance data presented in AJSM, there were a total of 4,492 players listed over the 21-year period who suffered 13,606 new injuries/illnesses. With regard to quad strains, from 1992 to 2002 there were 2.0 new injuries per club per season. That rate decreased to 1.8 from 2003 to 2012. The recurrence rate between those two time frames was 22 % and 13 %, respectively. The missed matches per club per season changed from 6.1 to 5.9 in the two time frames evaluated.

Quadriceps tendon rupture has generally been thought of as a condition of elderly patients. Typically this injury has been linked to patients with renal failure, diabetes, rheumatoid arthritis, hyperparathyroidism, connective tissue disorders, or steroid use. Thus, rupture amongst young, healthy athletes is not a common entity. When quad tendon rupture does occur among younger athletes, anabolic steroid use has been implicated [40]. This injury has been noted in the military athletes though [41]. A study from 2007 examined all orthopedic records at Womack Army Medical Center between 1995 and 1996. In this 2-year period there were 52 major tendon ruptures (Achilles, patella, pectoralis major, and quadriceps). Of the 52 ruptures, only four were quadriceps tendons (8 %). All four were in males who were of African descent. One rupture was the result of a basketball injury, one occurred while playing football, and two were classified as a result of "other" activities, which could include combat or direct blows to the anterior thigh.

Quadriceps contusion or hematoma is a common injury, but specific information on the epidemiology of this occurrence is even harder to come by than hamstring strain, or quadriceps strain or quadricep rupture.

Hägglund et al. reported prospectively collected data on professional soccer players in the Swedish premier league from the 2005 season [42]. Their study included 228 female players and 239 male players. They saw 28 thigh contusions in male athletes and 12 in females. Male players missed 4 ± 3 days because of this injury, and females missed 4 ± 1 days. Quadriceps contusion was the fourth most common diagnosis behind hamstring injury, adductor injury, and ankle inversion sprain.

Concerning quadriceps contusion and intercollegiate football players, the previous study mentioned [11] about college football tracked contusions to the upper leg. Again, data was tracked for 16 years and reported based on occurrence in fall games, fall practice, or spring practice. In fall games there were 1,129 upper leg contusions, which accounted for 3.7 % of injuries. This correlated to 1.27 events per 1,000 athlete exposures. In fall practices the respective numbers were 798, 1.9 %, and 0.07 contusions per 1,000 athlete exposures. Finally, in spring practice the numbers, respectively, were much lower at 190, 1.7 %, and 0.17 contusions per 1,000 athlete exposures.

In Australian football, data on quadriceps hematomas was reported in the 1997–2000 study that has been previously cited [16]. There were 0.9 quadriceps hematomas per club per season in these 4 years studied. The recurrence rate of this injury was only 5 %. There were 0.8 injuries per 1,000 match player hours in AFL matches. There were 0.1 non-match injuries per 1,000 player hours. On average, only 1.4 matches were missed per club for the entire season due to quadriceps hematoma or contusion. No thigh hematomas occurred in the preseason in this particular sport and study throughout this 4-year period. Then, the 20-year surveillance data was presented. During the 1992–2002 seasons there were 1.2 new thigh hematomas per club per season, and during the 2003–2012 interval there were 0.8 new hematomas per club per season. The recurrence rate was very low so it was grouped with other injuries and not separately reported. As far as games missed during the first 10-year interval, there were 1.8 missed matches per club per season due to this condition. During the second 10-year interval there were 1.1 missed matches per club per season.

One of the first studies that investigated quadriceps hematoma in New Zealand was published in 1982 [43]. This paper evaluated athletes from varying sports, not just rugby. But, the authors found that the highest rate of quadriceps hematoma and contusion in New Zealand does indeed occur in rugby football players. They followed 60 athletes to evaluate the natural history of the process, determine prognosis, and to discover optimum management of the injury. In their group of 60 patients they found the age range to be between 12 and 52 years old. Sixty percent of the group (36/60) had a quad contusion due to a rugby injury. Less common causes included accidentally bumping into a sedentary object, soccer (6/60), or basketball injuries (5/60). The most common causative agent of quadriceps contusions was a knee blow to the thigh (23/47), followed by shoulder blow, getting kicked, and head blow.

Specific data on quadriceps contusion rates in other college athletes is rather sparse besides the Injury Surveillance Studies cited throughout. It is a well-known entity in defensemen in college hockey players as a result of the puck contacting the anterior thigh in an attempt to block a shot [44]. The same 16-year data of the Injury Surveillance System was examined by Agel et al. to look at collegiate hockey players and quadriceps contusions/hematomas [45]. Per year they evaluated over 3,700 athletes participating in division I, II, and III intercollegiate hockey. They reported 292 upper leg contusions in games, and 74 in practices. This accounted for 6.2 and 3.8 % of all injuries, with knee internal derangement the most common injury in games and pelvis/hip tendon strains most common in practices. Per 1,000 athlete exposures in games there were 1.02 contusions, and in practices 0.07.

One collection of athletes prone to quad contusions and hematomas is those involved in martial arts. There have been several studies that have described this epidemiology, however one that was particularly well done with a larger cohort of patients was reported in Joint Bone Spine in 2006 [46]. One hundred eighty-six individuals from three karate clubs in Brest, France, were entered in a retrospective study extending from September 2002 to June 2003. Forty-eight of 186 athletes had some injury (28.8 %). Incidence of all injuries was similar between genders and the three clubs being reviewed. Injury rates increased with age, training hours, rank, and years of practice. Forty-three of the injuries (53 %) were hematomas. But, in looking closer at the data, the hematoma group included facial injuries such as nosebleeds. Hematomas of the thigh accounted for 14 % of this group, or six total injuries.

Injury to the hamstrings and quadriceps is a common entity, and affects a wide spectrum of athletes as delineated above. There has been a generous amount of literature that describes this occurrence in soccer, football, rugby, and Australian rules football players. The literature concerning adolescent athletes, females, and athletes in other sports is less abundant. Further understanding of the epidemiology of this occurrence will help with appreciating the true magnitude of the problem. Additionally, further investigation in the incidence and causes of these conditions can help to guide efforts in preventative measures and treatment regimens.

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Midsubstance Hamstring Injuries in the Athlete

4

Tadashi Takara, Omar Medina, Sharon L. Hame, and David R. McAllister

Hamstring Anatomy

The hamstring muscular complex is located in the posterior thigh and is primarily responsible for extension at the hip and flexion at the knee. The complex functions as a unit composed of three muscles (semimembranosus, semitendinosus, and the biceps femoris), which share a common point of origin at the ischial tuberosity (Figs. 4.1 and 4.2) [1].

The biceps femoris muscle is comprised of a long head and a short head, which additionally contribute to externally rotate the hip. Despite sharing a common insertion point on the lateral side of the fibular head, the short head differs slightly from the long head and other hamstring muscles in that it originates from the lateral lip of the linea aspera, located on the lateral supracondylar line of the femur [1, 2]. Further, the short head is innervated by the common peroneal division of the sciatic nerve (L5-S2), whereas the long head, semimembranosus and semitendinosus muscles are innervated by the tibial division of the sciatic nerve [1]. The semimembranosus and semitendinosus muscles additionally act to medially rotate the knee. After descending medially along the posterior thigh, the semimembranosus tendon divides into three main divisions: the oblique popliteal expansion, the anterior expansion, and the inferior expansion. Benninger et al. [3] found that the oblique popliteal ligament consists solely of a branch of the semimembranosus tendon and thus should be referred to as a tendon, not a ligament, as is commonly done. This branch spans across the popliteal fossa and inserts into the posterior capsule. The anterior division of the semimembranosus tendon extends its fibers to insert at the medial meniscus and medial collateral ligament [3]. The inferior division inserts at the posterior part of the medial condyle of the tibia [2, 3]. The semitendinosus muscle inserts along the superior part of the medial surface of the tibia, where it joins the tendons of the sartorius and gracilis muscles to form what is collectively called the pes anserinus. All muscles of the hamstring receive their blood supply from the perforating branch of the deep artery of the thigh and the superior muscular branches of the popliteal artery [1].

Hamstring anatomy is of clinical importance in injury assessment. The hamstring muscle

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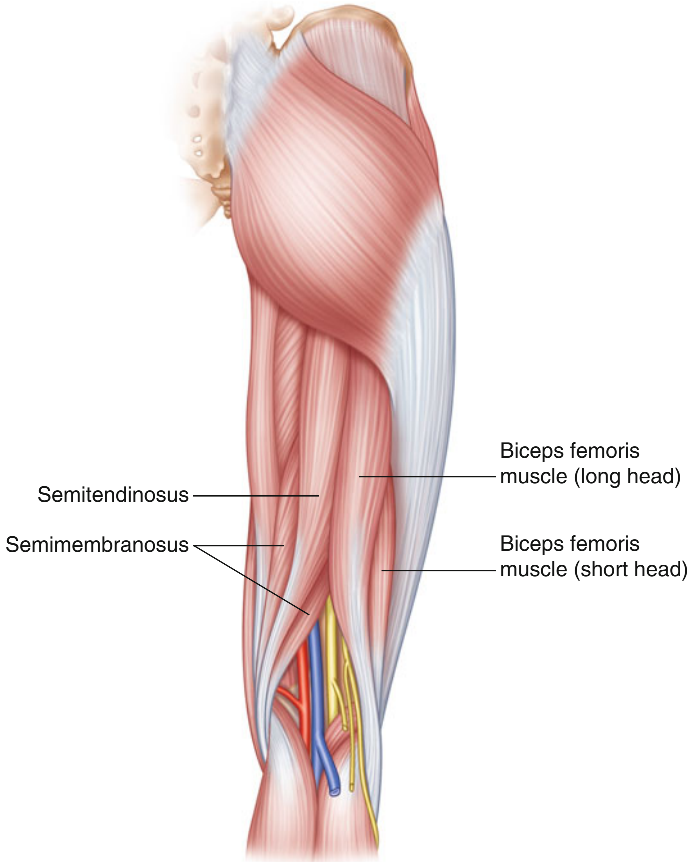

Fig. 4.1 Hamstring muscular complex located in the posterior thigh. Muscles of the complex include: the semimembranosus, semitendinosus, and the biceps femoris

complex is primarily used to decelerate while running, walking, or athletic motions such as sharp changes in the direction of motion at high speeds [4]. Through eccentric muscle contraction, these muscles serve to slow the lower limb during forward swing. Since the complex spans two joints, the hip and the knee, injury to any of the hamstring muscles can present with a wide range of symptoms [2].

Demographics and Risk Factors

Although injury to any of the muscles involved in the hamstring muscular complex can result from multiple complex interactions, modifiable and non-modifiable risk factors have been identified. Modifiable risk factors leading to hamstring injury include inadequate warm-up, increasing training volume, muscle fatigue, hamstring inflexibility and weakness, cross-pelvic posture, lumbar-pelvic weakness, and poor biomechanics during movement [5–11]. Risk factors that cannot be modified are seen in athletes of older age, a history of previous lower extremity injury, and may even be more common in African or Aboriginal ethnic backgrounds [8, 11–15].

Although the overall incidence of hamstring injuries in the general population is not known, athletes involved in competitive sports requiring sprinting and jumping are at particular risk. Bennell and Crossley reported a 14 % overall incidence of hamstring strains in track and field athletes [12], while Woods et al. reported that hamstring strains comprised 12 % of the total injuries in English professional soccer players over a two-season period [13]. Of these injuries, 53 % were found to involve the biceps femoris.

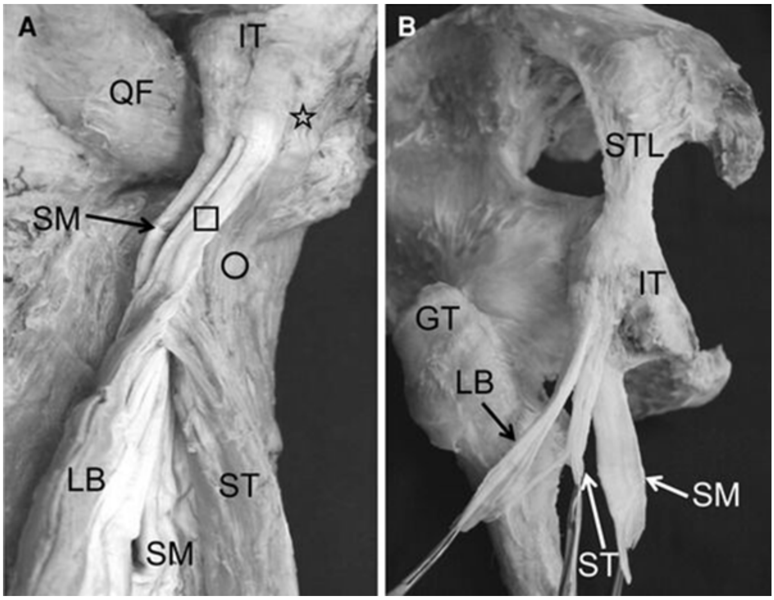

Fig. 4.2 (**a**) The origin of the long head of the biceps femoris and the semitendinosus (posterior, left-sided view of the left thigh). The long head of the biceps femoris originated from the posteromedial surface of the ischial tuberosity as a thick tendinous part (*square*), and the semitendinosus tightly adjoined the medial surface of the tendon of the long head of the biceps femoris as a muscular part (*circle*) and partly originated from the ischial tuberosity as a short and thin tendinous part medial to the tendon of the long head (*star*). (**b**) After removal of the muscular parts, the tendons of the hamstring muscles were observed. The semitendinosus muscle had a short and thin tendon which originated directly from the ischial tuberosity. *GT* greater trochanter, *IT* ischial tuberosity, *LB* long head of the biceps femoris, *QF* quadratus femoris, *SM* semimembranosus, *ST* semitendinosus, *STL* sacrotuberous ligament. With kind permission from Springer Science+Business Media: Journal of Orthopaedic Science, Anatomical study of the proximal origin of hamstring muscles, 17(5), 2012, Kengo Sato

Additionally, players of black ethnic origin and older age groups (23 or older) were found to have a significantly increased risk for hamstring strains.

Risk factors thought to be associated with hamstring strains include: history of previous hamstring injury, hamstring tightness, muscle fatigue, muscular strength imbalance, and insufficient warm-up. Orchard et al. followed 37 professional Australian rules football players and found a significant association between hamstring injury and both absolute hamstring weakness as well as a low hamstring-to-quadriceps muscle peak ratio [14]. However, the same study did not find a correlation between flexibility (tightness) and risk of injury. Although no data exist regarding the protective role of warm-up programs in relation to hamstring injuries specifically, one biomechanical study found that isometrically preconditioned muscles, similar to muscles subject to a warm-up period in athletes, required significantly more force to fail than non-preconditioned controls [15].

Mechanism of Injury and Grading Scale

In broad terms, the different types of hamstring injuries include: lacerations, contusions, delayed-onset muscle soreness, and strains. Muscle strains are the most common type of hamstring injuries and are the focus of this chapter. Hamstring strains occur most commonly at the musculotendinous junction of the hamstring musculature and are often a result of eccentric contractions [16]. Hip flexion combined with knee extension forces the hamstring musculature into maximum stretch which increases the risk for injury. Most injuries

Table 4.1 Clinical grades of hamstring strains[a]

Grade I	Mild injury with a tear of "a few muscle fibers" from overstretching of muscle
Grade II	Partial tear of muscle
Grade III	Complete tear of muscle

[a]Adapted from [17]

Table 4.2 Clinical grades of hamstring strains[a]

Grade I	<10° deficit
Grade II	10–19° deficit
Grade III	20–29° deficit
Grade IV	≥30° deficit

[a]Adapted from [18]

Table 4.3 Radiographic grades of hamstring strains[a]

Grade I	T2 hyperintense signal about a tendon or muscle without fiber disruption
Grade II	T2 hyperintense signal with fiber disruption of less than 50 % the width of the tendon or muscle
Grade III	Tendon or muscle disruption of greater than 50 % of the width of tendon or muscle

[a]Adapted from [19]

are noncontact and a high percentage occur during running. In their study, Woods et al. reported 91 % of hamstring injuries were noncontact while 57 % of them occurred while running [13].

Grading of hamstring injury has been based on the amount of muscle torn, clinical symptoms, range of motion at the knee, and magnetic resonance imaging (MRI). Zarins and Ciullo [17] described three grades of hamstring tear with grade II or partial tear being the most common (Table 4.1).

Malliaropoulos et al. [18] described a classification scheme the clinical severity of acute hamstring stains that relates the loss of active range of motion of the knee to the severity of injury (Table 4.2).

In addition to clinical classifications, radiologic grading schemes for hamstring strains (Table 4.3) have been developed by Shelly et al. [19].

An MRI study of 516 hamstring injuries in professional European soccer players from 23 teams examined the correlation of severity of hamstring injury grade on MRI to days of play/practice lost [20]. The number of days missed as a result of MRI grades 0, I, II, and III injuries was 8 ± 3, 17 ± 10, 22 ± 11, and 73 ± 60 days, respectively. The biceps femoris was noted to be injured 83 % of the time while the semimembranosus and semitendinosus were injured 11 and 5 % of the time. As expected, the severity of MRI findings correlated with days lost. As the quality of MRI improves, the classification of these injuries is expected to be better understood.

Clinical Presentation and Imaging

In most cases, athletes who suffer acute hamstring strains have a reliable clinical presentation (Fig. 4.3). They will often be seen grabbing their posterior thigh at the time of injury and be unable to continue performing their sport due to pain. They are likely to report pain isolated to the posterior thigh for a midsubstance injury with symptoms traveling more proximally for proximal injuries. Some athletes feel or hear an audible pop at the time of injury. On examination, posterior thigh ecchymosis may develop and weakness with resisted knee flexion may be evident. In some cases, there may be a palpable defect in the mid-thigh hamstring musculature.

Often, the diagnosis of a hamstring strain can be made clinically and imaging is unnecessary but it can have some value in diagnosing hamstring injuries. MRI can be useful in cases where the diagnosis is unclear. Ultrasound is another imaging modality that has been used in the diagnosis of hamstring injuries. A recent study by Petersen et al. [21] found no correlation between ultrasound findings and time to return to play in elite soccer players. In addition, of players with a clinical diagnosis of an acute hamstring strain, only 61 % had sonographic findings. The vast majority of hamstring strains can be diagnosed without imaging and are routinely treated without surgery.

Treatment

The goal of the initial treatment of acute hamstring strains is control of pain, edema, and hematoma formation. Ice and a compressive wrap are recommended for the first 24 h to help

Fig. 4.3 Clinical photo representative of a patient with a high-grade hamstring strain demonstrating posterior thigh ecchymosis. When present, the clinician should be suspicious of a high-grade hamstring strain

reduce hematoma formation. Protective weight-bearing should be initiated depending on the severity of the symptoms. In addition, oral nonsteroidal anti-inflammatory drugs are useful for early symptom control. Immobilization in the early post-injury phase aids in the formation of granulation tissue which is required for healing. Long periods of immobilization should be avoided as they can lead to muscle atrophy compromising optimal recovery of function and potentially increasing the rate of reinjury.

Oral nonsteroidal anti-inflammatory drugs are useful for early symptom control. In addition, injections to the injury site have been suggested and remain controversial. A study of severe hamstring injuries in 58 National Football League players treated with intramuscular corticosteroid injection reported favorable results [22]. In this study, only nine players missed any games and all athletes had full strength and normal muscle bulk and tone at final examination. The long-term outcome of corticosteroid injection to the hamstring musculature is unknown and further study on this area is necessary.

More recently, the injection of platelet-rich plasma (PRP) has been proposed as a possible treatment for acute hamstring injuries. A literature search reveals little data on the efficacy of PRP in the treatment of hamstring strains. In one study, Wetzel et al. reported the reduction of pain in patients with proximal hamstring injuries when treated with PRP when compared to traditional treatment [23]. Currently, there is not enough evidence to support or dissuade the use of PRP in the treatment of hamstring injuries.

After recovery from the acute post-injury phase, rehabilitation can begin. Depending on the grade of injury, protected weight-bearing can be instituted for up to 1 month followed by stretching and strengthening exercises (Fig. 4.4).

Fig. 4.4 Position for static hamstring stretching exercise. Hands are placed on a chair to stabilize the upper body. Ipsilateral hip is flexed approximately 90° while the knee is held near full extension. Athlete leans upper body forward to stretch hamstring. The left hamstring is being stretched in this photo. Reprinted with permission from Moss WR, Feland JB, Hunter I, and Hopkins T. Static stretching does not alter pre- and post-landing muscle activation. Sports Med Arthrosc Rehab Therap Technol 2011; 3:9. doi:10.1186/1758-2555-3-9. © 2011 Moss et al.; licensee BioMed Central Ltd

At our institution (a large university with a large division I sports program), athletes with hamstring injuries are treated primarily with an individualized rehabilitation program that is based on the achievement of milestones. A treatment protocol (Table 4.4) was presented in an article in the Journal of the American Academy of Orthopaedic Surgeons [24] and appears to be a reasonable general guideline. Ultimately, the patient's severity of symptoms and rate of recovery will dictate when to progress to the next phase of rehabilitation.

Prevention and Recurrence

Prevention of hamstring strains and recurrence of injury are imperative for a successful athletic career. As with other areas of frequent muscle strain or tear, eccentric strengthening may be helpful in preventing injury. There exist data on the prevention of initial hamstring injuries as well as recurrent injuries. A set of eccentric hamstring strengthening exercises known as Nordic exercises (Fig. 4.5) have been found to be effective at both increasing hamstring strength as well as preventing hamstring injuries in athletes. These exercises are performed with the athlete on their knees and a second person stabilizing their feet. The athletes are then instructed to let themselves fall forward and resist the fall against the ground as long as possible using their hamstrings.

A randomized control trial compared the effects of two different hamstring exercises in university soccer players over a 10-week period: the first exercise was the Nordic exercise and the second exercise hamstring curls. The trial demonstrated an 11 % increase in eccentric hamstring torque and 7 % increase in isometric hamstring strength, ultimately increasing the athletes' hamstring/quadriceps strength ratio [25]. Another study reported greater EMG activity and an increase in hamstring torque of up to 21 % in soccer players that underwent Nordic hamstring exercises compared to a control group [26].

A randomized control trial of 942 Danish professional and amateur soccer players showed that eccentric Nordic hamstring strengthening exercises significantly prevented acute hamstring injuries [27]. In that study, new injuries in players who did not undergo the strengthening exercises occurred at a rate of nearly triple that of those players who did (8.1 vs. 3.1 per 100 player seasons). The difference in recurrence rate between the two groups was even more dramatic at a rate of 45.8 vs. 7.1 per 100 player seasons in the Nordic group vs. the control group.

A prospective study of elite soccer players in Iceland and Norway also demonstrated the protective effect of the Nordic exercise. It showed teams that were assigned the eccentric training program had a reduced relative risk of 0.43 for the incidence of hamstring strains compared to teams who were not [28]. In addition, the study found that stretching exercises alone had no effect on the risk of injury. It should be noted that all of these studies used soccer players as the subjects but the data can reasonably be extrapolated to other athletes that also require sprinting and acceleration during their sport and are therefore at an elevated risk for hamstring injuries.

Table 4.4 Treatment protocol for hamstring strains[a]

Phase		Goals	Treatment
I (Acute)	3 to 5 days	Control pain and edema	Rest, ice, compression, elevation
	1 to 5 days	Limit hemorrhage and inflammation	Immobilization in extension, NSAIDs
	After 1 to 5 days	Prevent muscle fiber adhesions	Pain-free PROM (gentle stretching), AAROM
	Up to 1 wk	Normal gait	(Crutches)
II (Subacute)	Day 3 to >3 wks	Control pain and edema	Ice, compression, and electrical stimulation
		Full AROM	Pain-free pool activities
		Alignment of collagen	Pain-free PROM, AAROM
		Increase collagen strength	Pain-free submaximal isometrics stationary bike
		Maintain cardiovascular conditioning	Well-leg stationary bike, swimming with pull buoys, upper body exercise

(continued)

Table 4.4 (continued)

Phase		Goals	Treatment
III (Remodeling)	1 to 6 wks	Achieve phase II goals	Ice and compression
		Control pain and edema	Ice and electrical stimulation
		Increase collagen strength	Prone concentric isotonic exercises, isokinetic exercise
		Increase hamstring flexibility	Moist heat or exercise prior to pelvic-tilt hamstring stretching
		Increase eccentric loading	Prone eccentric exercises, jump rope
III (Functional)	2 wks to 6 mo	Return to sport without reinjury	Walk/jog, jog/sprint, sport-specific skills and Drills
		Increase hamstring flexibility	Pelvic-tilt hamstring stretching
		Increase hamstring strength	Prone concentric and eccentric exercises
		Control pain	Heat, ice, and modalities; NSAIDs as needed
V (Return to competition)	3 wks to 6 mo	Avoid reinjury	Maintenance stretching and strengthening
Abbreviations: AAROM= active-assistive range of motion; AROM= active range of motion; NSAIDs= nonsterodial anti-inflammatiory; PROM= passive range of motion			

[a]Reprinted with permission from Clanton TO, Coupe KJ. Hamstring strains in athletes: diagnosis and treatment. J Am Acad Orthop Surg. 1998 Jul-Aug;6(4):237-48.

AAROM active-assistive range of motion, *AROM* active range of motion, *NSAIDs* nonsteroidal anti-inflammatory drugs, *PROM* passive range of motion

[a]Reprinted with permission from Clanton TO, Coupe KJ. Hamstring strains in athletes: diagnosis and treatment. J Am Acad Orthop Surg. 1998;6(4):237–48

Intuitively, one would be led to believe that the higher the grade of the initial injury, the higher the recurrence rate. A different 2011 level I study of 165 elite track and field athletes did not support this. The study reported no difference in the reinjury rate between acute low-grade injuries (grades I and II) when compared to high-grade injuries (grades III and IV) in this population over a 24-month period post-injury [18]. Based on this data, an athlete with a first time acute hamstring strain can be counseled that the severity of initial injury does not correlate with reinjury rates and that regaining hamstring strength is a more important factor

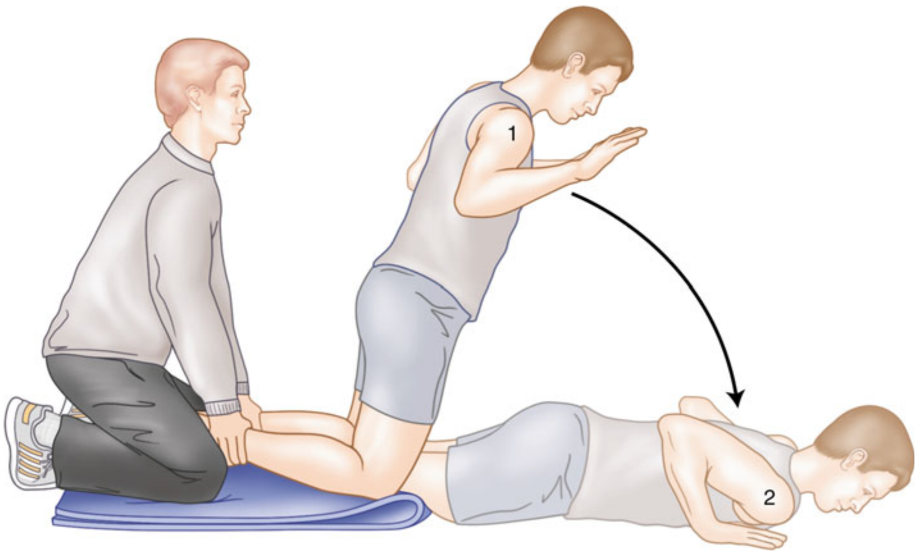

Fig. 4.5 Nordic eccentric hamstring exercise. Athlete is positioned on their knees and a second person stabilizes their feet. The athlete is then instructed to let themselves fall forward and resist the fall against the ground as long as possible using their hamstrings

in preventing reinjury. In addition, recurrent injuries tend to happen within 2 weeks of return to sports [29].

To contrast, a 2010 study of 59 elite Australian rules football players [30] found a correlation between the ability for an athlete to walk pain-free within 1 day post-injury and time to return to competition. The odds ratio was 4.0 for an athlete taking more than 1 day to walk pain-free after a hamstring injury in relation to taking more than 3 weeks to return to competition. They also found an odds ratio of 19.6 for the risk of recurrence for players who had a hamstring injury in the prior 12 months.

A study of over 1,000 football players at the University of Nebraska demonstrated that there was a significant difference in the rates of recurrent hamstring injuries between players who had regained near-normal hamstring strength prior to returning to play and those who did not (0 vs. 31.7 %) [31]. They considered a player to have regained near-normal hamstring strength at 95 % of a baseline score or a hamstring/quadriceps ratio of 0.55 or greater. These were the return to play criteria for the treatment group which had a lower rate of reinjury compared to the control group. Again, the data support the notion of using strength as criteria for return to play.

In summary, the reported data indicate that eccentric hamstring strengthening exercises are important for the prevention and recurrence of hamstring injuries in athletes, while the original grade of injury does not correlate with the rates of recurrence. The use of eccentric exercises in rehabilitating athletes with hamstring strains and ensuring they have full or near full strength prior to return to play also appears important.

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Acute Proximal Hamstring Tendon Avulsions

5

Timothy L. Miller

Introduction

Proximal hamstring avulsions are relatively uncommon injuries in the general population but occur more frequently with athletic participation at all skill levels. The biceps femoris tendon is the most frequently injured tendon, with injuries most often occurring during the take-off phase of the gait cycle. The semitendinosus tendon is the next most commonly injured proximal hamstring tendon, with strains and tears occurring most often during the swing phase of gait [1]. These injuries are particularly common among athletes who participate in sprinting, hurdling, and water skiing [2].

Mechanism of Injury

The most commonly reported mechanism for proximal hamstring tendon avulsions involves a sudden eccentric contraction of the hamstrings with the hip in flexion and the knee in extension, as may occur during sprinting, hurdling, or water skiing [3, 4]. Because of the increased forces applied, injuries that occur by a water skiing mechanism have been noted to be more severe when compared to those that occur during sprinting [5]. Animal studies have demonstrated that eccentric loads of fatigued muscles result in significantly more damage than isometric or concentric loads [6].

In the case of novice water skiers, the upper torso is forcefully pulled forward, causing subsequent rapid eccentric hip flexion and knee extension against the resistance of the water and ski (Fig. 5.1) [5]. With more advanced water skiers, injuries may occur when the ski tips get caught in the wake during turns or while falling [5]. Additionally, these injuries may occur in sprinters at the time of an acute change in speed or direction or in dancers or gymnasts performing prolonged extreme stretching of the hamstring [6].

Risk Factors for Proximal Hamstring Injury

Multiple risk factors have been reported for proximal hamstring injuries. In the National Football League, the preseason has been identified as the most vulnerable time frame for hamstring injuries due to relative deconditioning and weakness [7]. The most commonly described risk factors include previous hamstring injury [2, 8, 9], poor lower extremity flexibility [10, 11], core instability [12, 13], dehydration, strength imbalance [14, 15], fatigue [1, 16], and an inadequate warm-up

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Fig. 5.1 Water skiing mechanism of injury. As the boat accelerates, the upper torso is forcefully pulled forward, causing subsequent rapid eccentric hip flexion and knee extension against the resistance of the water and ski

[17]. A previous hamstring injury may lead to the formation of weakened scar tissue at the injury site, thereby lowering the capacity of the myotendinous unit to resist secondary injury [16, 18, 19]. Strength imbalance refers to either disproportionate hamstring-to-quadriceps strength in the same limb or the difference in hamstring strength between opposite lower extremities. With regard to the warm-up, increasing muscle temperature in order to prevent injury remains somewhat controversial but may increase the ability of the muscle tendon unit to resist strain [6, 17].

Clinical Presentation

At the time of an acute injury most athletes describe a sudden sharp pain in the posterior thigh or buttock. An audible or palpable pop may be associated with the pain. Classically described during the take-off phase of water skiing when the torso is pulled forward and the skis are pulled against the resistance of the water as mentioned earlier, this injury may also occur with sprinting, jumping, and kicking sports [4, 5, 20]. A smaller subset of individuals may describe progressive hamstring tightness eventually leading to an acute on chronic tear [6]. These injuries may present initially as discomfort with sitting [4, 6].

Differential Diagnosis

The differential diagnosis for proximal hamstring tendon avulsion includes the following [21, 22]:

Neurologic
- Lumbar radiculopathy
- Sciatica
- Piriformis syndrome

Vascular
- Arterial pathology (peripheral arterial disease/ pseudoaneurysm/endofibrosis)
- Venous pathology (pelvic deep vein thrombosis)
- Compartment syndrome

Myotendinous
- Hamstring strain or tear
- Gluteal muscular tears

Traumatic/bony
- Ecchymosis/bruising
- Morel-Lavallee lesion
- Ischiogluteal bursitis
- Insufficiency fracture of pelvis (stress reaction)
- Acute pelvic fracture
- Apophysitis
- Avulsion fracture of the ischial tuberosity
- Sacroiliac joint pathology

On-the-Field Evaluation

Initial on-the-field or sideline evaluation of a suspected proximal hamstring injury should follow established trauma protocols, particularly if a fracture is suspected. Once the athlete is in a safe area (ideally on the sideline or out of the field of play) a more detailed and focused evaluation should be performed, including a thorough neurovascular examination. If the injury was not witnessed by the clinical evaluator, then the athlete, teammates, or coaches should be questioned to ascertain the mechanism of the injury. Further history taking should include a discussion of any previous injuries to the affected site.

Sideline physical examination should assess the point of maximum tenderness (i.e., origin, musculotendinous junction, mid-muscle belly, or distal hamstring). These areas should be further inspected and probed for any palpable soft tissue defects. Furthermore, the ischial tuberosity should be palpated for possible fracture. Motor strength should be assessed by grading the ability to flex the knee against resistance on a 0–5 scale. Knee flexion strength testing should be performed with the athlete prone and strength tested with knee at 90° of flexion, 45° of flexion, and at 0–10° of flexion. The athlete's gait should be evaluated for pelvic drop, abnormal gait, ability to heel drag, and the ability to initiate a sprint. A stiff-legged gait may also be noted.

Evaluation of the tension of the distal portion of the hamstrings with the patient supine and with the hip and knee flexed to 90° is required for identifying proximal hamstring ruptures. The absence of palpable tension of the distal portion of the hamstrings, referred to as a positive bowstring sign, may be present. This sign suggests that there has been excessive lengthening of the proximal part of the tendons or complete proximal hamstring rupture [23].

Physical Examination

Physical examination in the office setting includes a repeat neurovascular examination to rule out lumbar spine and sciatic nerve pathology as well as any peripheral vascular concerns. The neurologic examination should also include assessment of the function of the tibial and peroneal branches of the sciatic nerve [21, 24]. When affected the athlete may experience a foot drop with possible ankle eversion weakness [25]. Additionally, a stiff-legged or antalgic gait may be noted when the patient is observed walking [4].

The thigh and buttock should be inspected with the patient prone. The evaluation should note any visible or palpable soft tissue defect. Severe ecchymosis is commonly present at the posteromedial thigh in the first 1–2 weeks following an acute tendon rupture (Fig. 5.2). The point of maximal tenderness should again be determined by palpation including palpation of the ischial tuberosity. Strength testing should again be performed prone with resisted knee flexion at 0–10°, 45°, and 90° of flexion and graded as described above.

Fig. 5.2 Photograph of ecchymosis of the posterior thigh 5 days after proximal hamstring rupture

The Reverse Plank test is a specific test that should be performed to evaluate hamstring function [4, 26]. This test (Fig. 5.3) is performed by having the patient supine and resting on the heels and flexed elbows. The core is contracted and the buttocks are lifted off the floor or examination table while the uninjured lower extremity is lifted forward. Pain and inability of the injured limb to elevate the buttocks off the floor is indicative of a hamstring injury. The standing heel-drag test is performed by having the patient drag the heel of the affected lower extremity against the friction of the floor in an anterior to posterior direction. The test is performed bilaterally with a positive result occurring when pain or discomfort is elicited at the ischial tuberosity of the injured limb [26].

Multiple other special provocation tests have been described to evaluate for hamstring injuries [6]. The Puranen–Orava test (Fig. 5.4a) is performed with the patient standing with the hip flexed to 90° and the knee fully extended [6].

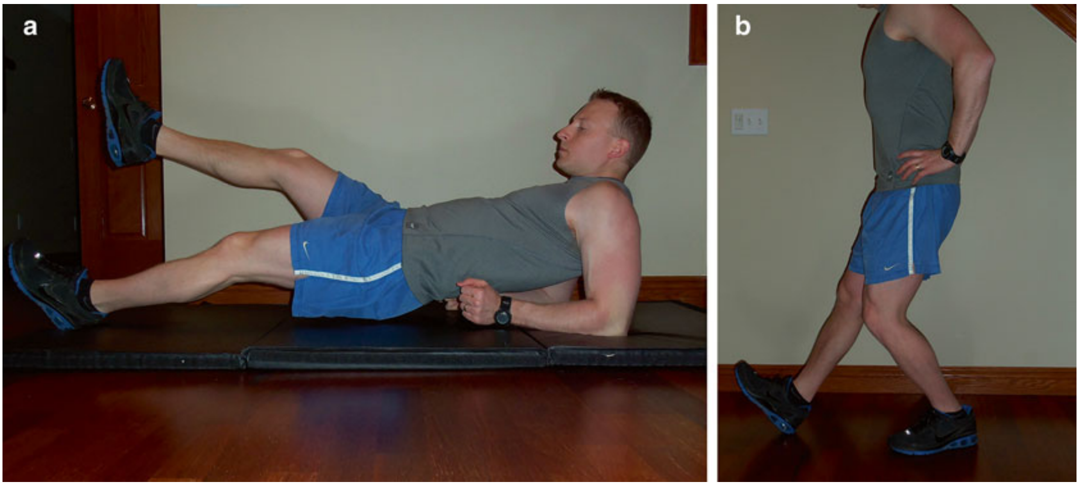

Fig. 5.3 (**a**) Reverse plank test. Examinee is supine and resting on the heels and flexed elbows. The buttocks are lifted off the floor or table while the uninjured lower extremity is lifted forward. Pain and inability of the injured limb to elevate the buttocks off the floor are indicative of a hamstring injury. (**b**) Standing heel-drag test. Examinee drags the heel of the affected lower extremity against the friction of the floor in an anterior to posterior direction. Test is positive when pain is reproduced at the ischial tuberosity

The examinee's heel is held on a support by the examination table, a chair back, or railing. For the bent-knee stretch test the patient is supine and the hip and knee of the injured extremity are maximally flexed [6]. The examiner then slowly passively extends the knee. The modified bent-knee stretch test (Fig. 5.4) is also performed with the patient supine. The examiner maximally flexes the hip and knee and then rapidly extends the knee. For all tests described above, tendinosis, strain, or potential rupture of the hamstring is indicated by increased posterior thigh pain with extension of the knee. This series of examination tests has shown moderate to high validity and reliability for identifying hamstring injuries [6, 27].

Imaging

Radiographs

Imaging evaluation in a patient with a suspected proximal hamstring injury should include an anterior/posterior X-ray view of the pelvis [4, 28]. Orthogonal views should also be obtained of the femur of the injured limb to confirm there is no associated proximal femur fracture present. Radiographs are typically normal but may be reveal an avulsion fracture of the ischial tuberosity [4, 28].

MRI

If radiographs are normal, magnetic resonance imaging (MRI) is recommended for making an accurate diagnosis. T2-weighted MRI series further assist in determining the pattern and severity of soft tissue injury including the number of tendons injured, complete versus partial rupture, chronicity, and the amount of tendon retraction (Fig. 5.5). Chronicity of the injury can be determined on T2 MRI based on the amount of fibrosis present [6, 29]. Additionally, MRI can determine the degree of soft tissue damage by defining the dimensions of abnormal T2 signal within and around the tendon substance, percentage of abnormal cross-sectional tendon substance, and extent of increased T2 signal intensity [30]. For proximal hamstring injuries, images should capture the ischial tuberosities and proximal thighs. Partial-thickness tears of the proximal hamstring complex may also be identified by a linear signal at the tendon–bone interface present on axial T2 images. This linear, crescent-shaped signal is referred to as the "sickle-sign" [26].

Fig. 5.4 (**a**) Puranen–Orava test. (**b**, **c**) Bent-knee stretch test. (**d**, **e**) Modified bent-knee stretch test

Ultrasonography

Recently ultrasound has increased in popularity and usefulness for identifying and classifying proximal hamstring ruptures. Ultrasonography has been demonstrated to be highly accurate in the acute setting for determining the extent and location of a hamstring tear [6, 18, 31]. This modality provides high-resolution imaging allowing for direct correlation with clinical examination and more immediate imaging [18]. The advantages of this technique include its relative inexpense, its high sensitivity and specificity, and its increasing availability in clinics and emergency department settings. The greatest disadvantage of using ultrasound for diagnosis of

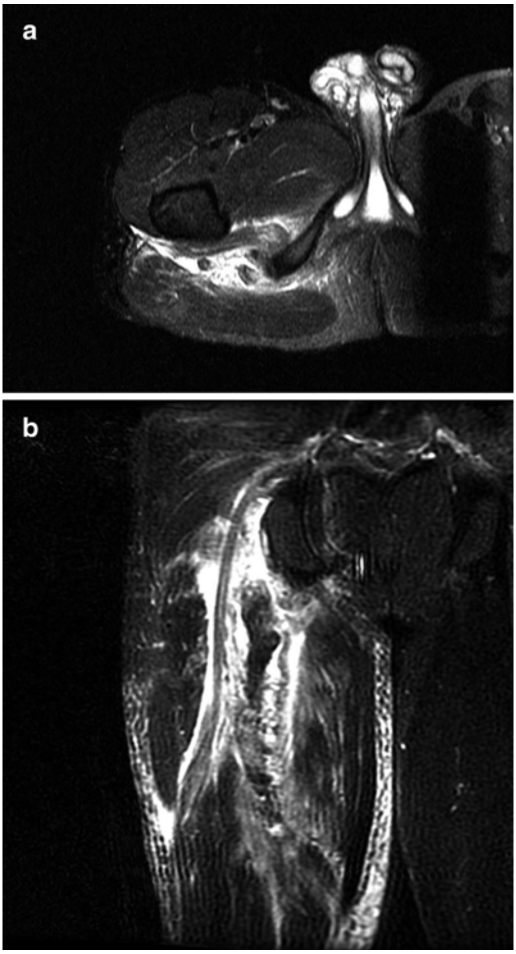

Fig. 5.5 (**a**, **b**) Axial and coronal cut T2 MRI demonstrating acute complete proximal hamstring avulsion tear with retraction

proximal hamstring tendon avulsion is that its accuracy is often dependent on the operator's level of experience (Fig. 5.6).

Classification

Hamstring injuries have been classified based on the anatomic site, pattern, and severity of the injury in the acute stage, as assessed by MRI or ultrasound [2, 6, 30, 32, 33]. Wood et al. described a clinical and anatomic classification system based on pattern of the tear and patient symptoms [1] (Table 5.1). Shelly and associates have described an MRI grading system for muscle injury that is commonly used to categorize hamstring injuries. In this system grade 1 is defined by a T2 hyperintense signal about a tendon or muscle without fiber disruption, grade 2 as a T2 hyperintense signal around and within a tendon with fiber disruption less than half the tendon width, and grade 3 as disruption greater than half its width [34]. Neither clinical nor radiologic classifications, however, have been precisely correlated with time to return to play after a hamstring injury.

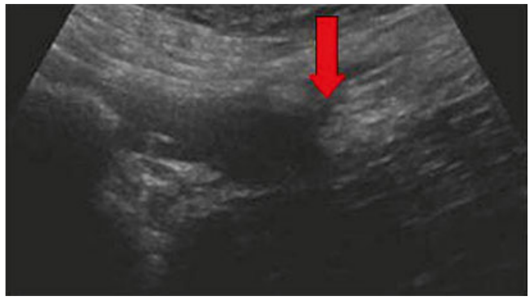

Fig. 5.6 Longitudinal ultrasound image demonstrating retracted proximal hamstring avulsion rupture. *Arrow* points to biceps femoris stump

Table 5.1 Classification of proximal hamstring tendon injuries[a]

•	Type I:	Bony avulsion
•	Type II:	Proximal MTJ tear
•	Type III:	Incomplete avulsion
•	Type IV:	Complete avulsion—w/o retraction
•	Type V:	Complete avulsion—retracted
		A. + sciatic nerve symptoms
		B. − sciatic nerve symptoms

[a]Adapted from [33]

A more detailed MRI scoring system has been devised by Cohen et al. [35] based on eight features. These include (1) player age, (2) number of muscles involved, (3) location of injury, (4) presence of insertional damage, (5) percentage of cross-sectional muscle involvement, (6) length of muscle retraction, (7) long-axis T2 sagittal plane signal abnormalities, and (8) presence of chronic changes. Recovery time >2 to 3 weeks was associated with multiple-muscle injury, >75 % cross-sectional involvement, presence of retraction, circumferential edema, and an MRI score of >15 [35]. This scoring system was found to be highly predictive of time missed from athletic participation [6].

Ischial Tuberosity Avulsion Fracture

Avulsion fractures of the ischial tuberosity typically occur in younger athletes particularly in the pediatric population as the child approaches skeletal maturity [36–38]. As with tendinous avulsions, these injuries typically result from a sudden forceful flexion of the hip joint while the knee is extended and the hamstring is contracted. Patients report sudden pain of the proximal, posterior thigh and a palpable or audible crack following a violent muscle contraction [22]. Clinical presentation typically includes localized pain and swelling, limited hip motion, and pain with sitting. Radiographs of the pelvis in the anterior to posterior plain should be performed for patients with suspected ischial tuberosity fracture and correlative clinical findings (Fig. 5.7). Fractures may be nondisplaced to widely separated with or without comminution. Occasionally a pseudarthrosis or an enlarged ischial mass may develop leading to chronic pain [39]. When radiographs are inconclusive, MRI or ultrasound may be required to evaluate soft tissue injury of the proximal hamstring as described above. As with all fractures, prompt and accurate diagnosis is essential for providing optimal treatment.

Because of the limited literature on the treatment of ischial tuberosity avulsion fractures, there is no clear algorithm for the management of this injury [22, 37, 40]. Nonoperative treatment with activity modification and use of a cushioned seat are the mainstays of treatment for the vast majority of patients. An adequate period of rest and activity modification facilitates the best outcomes from conservative management [41]. Failure to heal with nonoperative treatment and/or displacement of greater than 2 cm are relative indications for surgery. However, there is no clearly defined amount of displacement that confirms the need for surgery [41]. A multitude of surgical options have been described to treat avulsions fractures including open reduction and internal fixation [22] and excision of the bony fragment [39] with or without repair of soft tissue to bone [41]. Potential complications of conservative treatment include nonunion of the avulsion fractures and "hamstring syndrome" in which shortening and fibrosis develop at the origin of the hamstrings [42]. An adequate period of rest and modified training seems to be important to facilitate optimal outcome of conservative treatment [41].

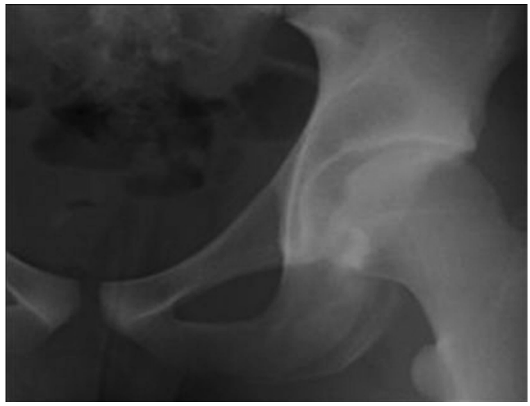

Fig. 5.7 AP pelvis radiograph demonstrating right ischial tuberosity avulsion fracture

Most authors recommend operative treatment in fractures with displacement greater than 2 cm [41]. Ferlic et al. found that in the acute setting operative treatment led to excellent outcomes for displacement of fractures greater than 1.5 cm [41]. Gidwani and associates recommend early operative treatment in patients with displacement of more than 1 cm [43]. Multiple surgical options have been utilized including plate fixation and screw fixation [22, 43]. Surgical approaches via the gluteal crease or a modified Kocher–Langebeck approach may be performed with the patient placed prone and flexed or in the lateral decubitus position with the injured side positioned up and the limb draped free. Figure 5.8 demonstrates a displaced ischial tuberosity fracture post open reduction and internal fixation. Postoperative rehabilitation follows similar protocols as will be described later for tendinous avulsions.

Fig. 5.8 AP pelvis radiograph following fixation of ischial tuberosity avulsion fracture

Table 5.2 Treatment recommendations for proximal hamstring tendon avulsions

Single-tendon avulsion (with retraction 1–2 cm)
Nonoperative treatment
Return to sport at approximately 6 weeks postinjury
Two-tendon rupture: Controversial (literature not well established)
Nonoperative treatment for older (>50 years of age) and low-demand patients
Surgical repair for:
– Young patients (<50 years of age)
– Athletically active patients
– Tendon retraction >2 cm
Three-tendon avulsion:
Surgical repair

Management of Proximal Hamstring Avulsions

As with ischial tuberosity avulsion fractures, early diagnosis and prompt treatment are the keys to the management of proximal hamstring avulsions. Activity level of the patient affects treatment decision-making with surgery being recommended more often for highly active patients. Delay in surgical treatment allows for greater tendon retraction making repair more difficult and increasing the risk of complications and inferior outcomes [44, 45]. Long-term sequelae of a neglected hamstring avulsion include pain, weakness, poor endurance, and sciatica due to tethering of the retracted muscle to the sciatic nerve [46]. A recommended treatment protocol is shown in Table 5.2.

Nonoperative Management

Nonoperative treatment is appropriate for proximal hamstring injuries involving only one tendon or if multiple tendons are involved but retraction is minimal [4]. This option is reserved for one- or two-tendon ruptures with less than 2 cm of retraction [4]. Nonoperative treatment is less successful for more significant injuries including complete three-tendon tears regardless of the extent of retraction [4, 6, 44, 45]. Less active patients, those with medical comorbidities, and patients unable to comply with postoperative rehabilitation are also indications to manage these injuries nonoperatively [6]. One notable complication of nonoperative treatment is hamstring syndrome. This is characterized by posterior buttock pain, discomfort with sitting, and worsening pain when performing hamstring stretching and strengthening exercises [6, 47].

Nonoperative management consists of rest, activity modification, anti-inflammatory medications and physical therapy. Once pain from the injury resolves core (abdominal and paraspinal), hip, and quadriceps exercises are added to the rehabilitation protocol [48]. Modalities proposed to improve symptoms and potentially speed recovery include ultrasound, shockwave therapy, and electrical stimulation [49]. These injuries may take up to 6 weeks for the tendon to heal via fibrosis to the intact tendons, often allowing the initiation of limited activity at that point. However, symptoms from many tears managed nonoperatively can persist beyond the normal healing times. Full return to sports participation is permitted when pain has resolved and strength has returned to >90 % of the contralateral hamstring [48].

Operative Management

Surgical Indications

Surgical indications suggested by multiple authors for proximal hamstring injuries include those that involve all three tendons (semitendinosus, semimembranosus, and the biceps femoris long head) as well as some two-tendon tears with more than 2 cm of retraction [4, 6, 23, 33, 44, 47, 50–52]. Additionally, operative treatment is recommended for partial tears when nonoperative treatment is unsuccessful [4, 23, 33].

Timing of Repair

Proximal hamstring avulsions that require surgery are best managed within 4 weeks of injury [6]. Some studies have suggested that delayed repair is associated with poorer results and reduced hamstring strength and endurance [5, 33, 50], while other studies have shown no difference [23, 24, 51]. Brucker et al. reported on eight patients, six of whom had surgery within 2 weeks after the injury, one at 9 weeks, and one at 22 weeks. Those authors found no difference in postoperative isokinetic testing between the groups [24]. Likewise, Klingele et al. found no difference in postoperative isokinetic testing between chronic (i.e., repair more than 4 weeks after injury) and acute (i.e., repair less than 4 weeks after injury) surgical repairs [51]. Sarimo and associates reported on 41 patients with proximal hamstring injuries, 29 of whom had good or excellent results after having surgery an average of 2.4 months from the time of injury. The remaining 12 patients had moderate or poor outcomes at an average surgical delay of 11.7 months from injury [23, 50].

Surgical Technique Options

Endoscopic Repair

There have been many series and descriptions of open surgical techniques for proximal hamstring repair but very few for endoscopic techniques [53, 54]. With the significant increase in use of the arthroscopy of the hip proximal hamstring repair via this technique is a developing option for repair. In experienced hands, this procedure allows for complete exposure of the posterior aspect of the hip in a safe, minimally invasive fashion. The expected benefits of this approach are no requirement for elevation of the gluteus maximus and greater ability to protect the sciatic nerve [53, 54].

The technique positions the patient prone. Two endoscopic portals are created, 2 cm medial and lateral to the palpable ischial tuberosity, respectively. A 30° arthroscope is inserted in the lateral portal, and an electrocautery device is placed in the medial portal to remove any remaining fibrous tissue from the bony attachment. The hamstring footprint is then undermined, and the lateral ischial wall is debrided with an oscillating shaver. The devitalized tissue is removed, and a vascular bone bed is created in preparation for suture anchor insertion. A third portal is created approximately 4 cm distal to the tip of the ischium. Once the suture anchors have been drilled and inserted into the bone bed, a suture passing device is then used for the repair. Once this point is reached, the principles of repair are analogous to those used in arthroscopic rotator cuff repair [53].

One concern for the endoscopic approach includes fluid extravasation into the pelvis as a result of the fluid used in the distension of the potential space around the hamstring tendon. Additionally, iatrogenic injury to the sciatic, posterior femoral cutaneous, and inferior gluteal nerves remains a risk. However, given that no retraction is required, these risks are theoretically lessened [53, 54].

Preoperative Planning and Positioning for Open Repair

Open repair of a proximal hamstring avulsion requires that the patient is fully anesthetized and positioned prone with the trunk in approximately 20° of flexion at the waist (Fig. 5.9a, b) [6, 55]. The affected lower extremity is draped free to allow access to the gluteal crease and unrestricted knee flexion. Preparation and draping of the limb may be more easily performed by hanging the limb from a fixed suspensory device such as an IV pole with a padded stirrup to hold the limb elevated by the ankle while the limb is cleansed [46].

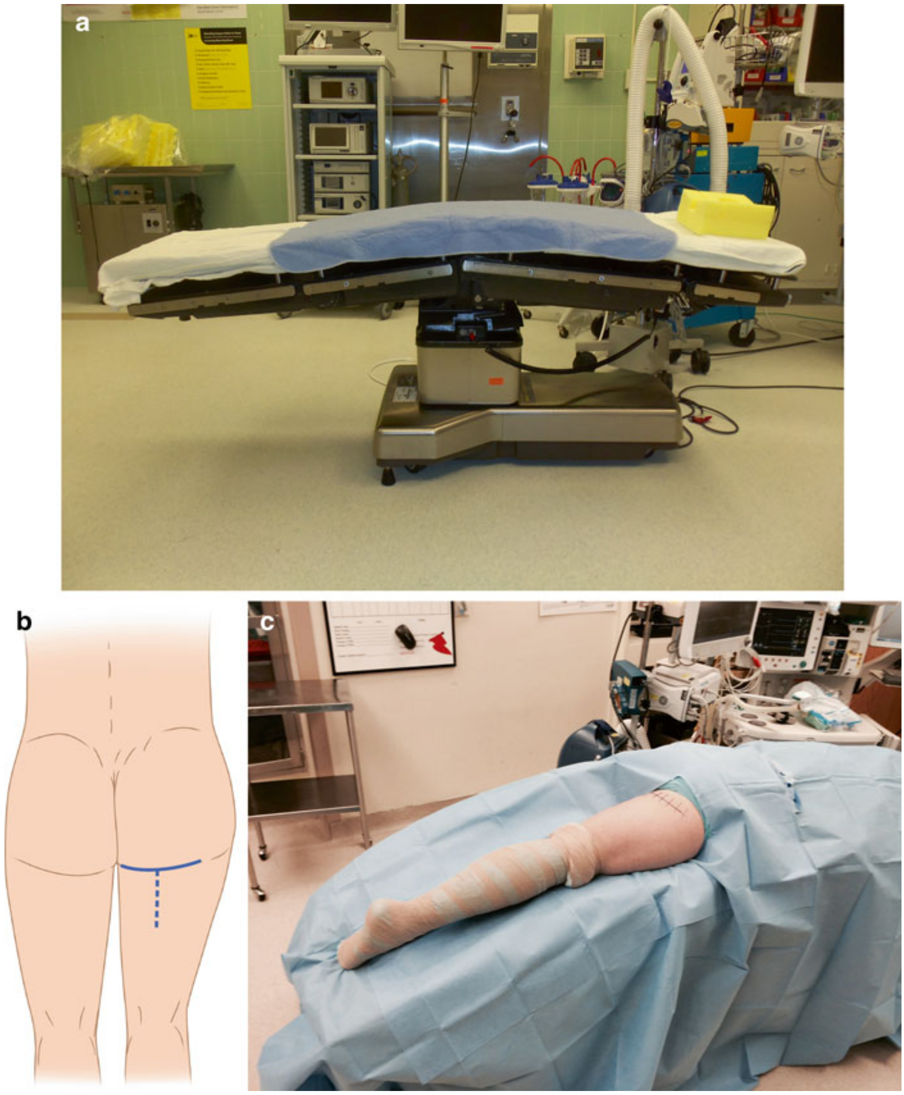

Fig. 5.9 (**a**) Operative table position for exposure of gluteal crease: 20° of flexion. (**b**) Transverse incision is made in the inferior gluteal crease to improve cosmesis and access to the retracted tendons. (**c**) Intraoperative photograph of patient, position, draping, and planned incision

Surgical Anatomy and Open Surgical Approach

Surgical approach to the avulsed proximal hamstring tendons and the ischial tuberosity is performed through a transverse incision at the gluteal crease (see Fig. 5.9b, c). Longitudinal and T-shaped incisions have been described but are typically less cosmetically pleasing [51, 55]. The dissection proceeds through the subcutaneous tissue to expose the gluteal fascia taking care to protect the posterior femoral cutaneous nerve and its branches. The gluteal fascia is then incised in line with the skin incision. The gluteus maximus is elevated and retracted superiorly or split over the ischial tuberosity to expose the hamstring fascia [6]. The hamstring fascia is then split longitudinally to expose the torn tendons. When the repair is not performed acutely, scar tissue may envelop the damaged tendons giving the impression of intact tendons. Scar tissue is excised and any seroma or hematoma is evacuated from the surgical field. The remaining tendons are then mobilized, debrided, and tagged with suture for later repair.

The sciatic nerve may be exposed and a neurolysis performed at this time if the patient displays signs of sciatic nerve injury preoperatively. Otherwise, the nerve may be protected by retracting the hamstring tendons laterally as the ischial tuberosity is exposed and prepared [6]. A periosteal elevator, small rongeur, or curette is used to clear the soft tissue remnant from the lateral aspect of the ischial tuberosity [55]. A bleeding bone bed is then prepared at the insertion site to increase healing potential at the bone–soft tissue interface and allow application of the fixation devices [55]. A motorized burr is not recommended for this step due to risk of injury to the nearby neurovascular structures. Alternatively, a small osteotome may be used to create longitudinal stripes at the insertion and prepare the vascular bed. The bone should not be completely decorticated as this may lead to pullout of the fixation devices [6].

Fixation

For fixation of reattached tendons, suture anchors are placed in an "X" pattern into the ischial tuberosity perpendicular to the facet of the hamstring origin (Figs. 5.10 and 5.11). The semimembranosus tendon is located anterior and lateral to the long head of the biceps femoris and the semitendinosus tendons [55, 56]. The semimembranosus footprint is crescent shaped and lies lateral to the semitendinosus and biceps femoris footprint [56]. The semitendinosus and biceps femoris share an oval-shaped footprint 2.7 cm long and 1.8 cm wide [56] (Fig. 5.12). Five anchors inserted into the anatomic location of the proximal hamstring tendons is recommended [55]. The knee is held flexed at 30–60° to decrease tension on the repair. The sutures are then passed through the tendon in a similar "X" configuration and tied in a horizontal mattress fashion from inferior to superior [55]. Chronic tendon ruptures may require an allograft soft tissue bridge due to retraction of the tendons distally away from the

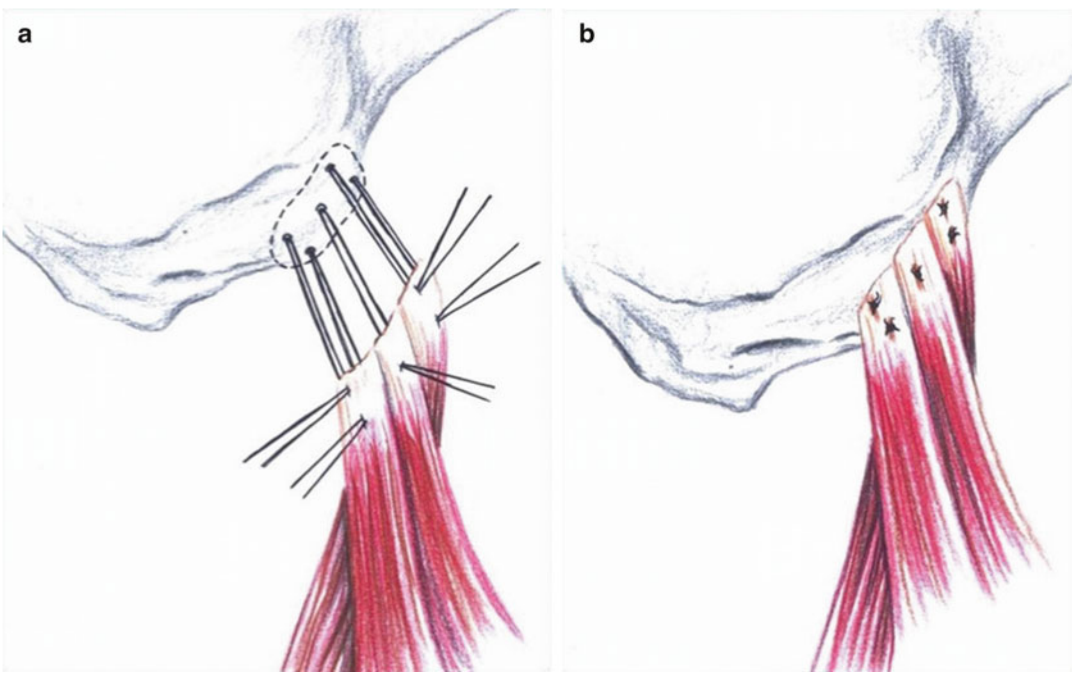

Fig. 5.10 (**a**) X configuration of suture anchors placed at the ischial tuberosity with sutures passed through the tendons. (**b**) Sutures tied distal to proximal securing tendon to bone. Reprinted with permission from Dr. James Bradley

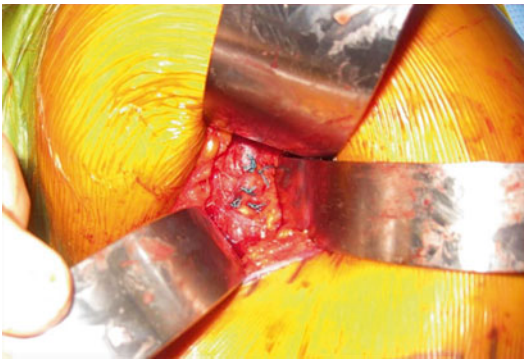

Fig. 5.11 Intraoperative photograph demonstrating the X configuration of suture anchors following repair of proximal three-tendon hamstring avulsion tear

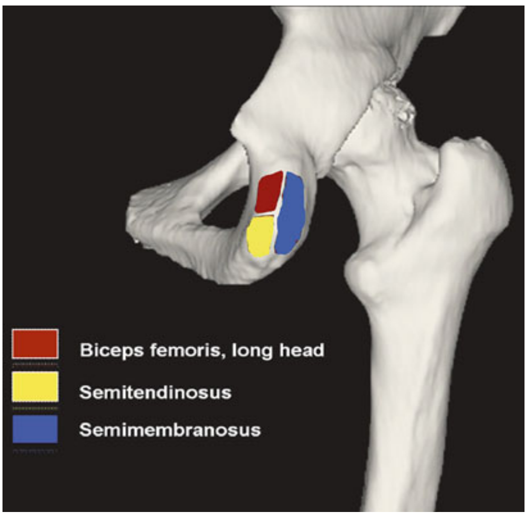

Fig. 5.12 Three-dimensional CT scan of the right hemipelvis demonstrating the insertion sites of the proximal hamstring tendons. Ahmad CS, Redler LH, Cicotti MG, Maffulli N, Longo UG, Bradley JP, American Journal of Sports Medicine (vol. 41, issue 12) pp. 2933–2947, copyright © 2013 by SAGE Publications. Reprinted by permission of SAGE Publications

tuberosity. This gap may be covered by employing an Achilles tendon allograft [6].

Risks and Complications

Intraoperative complications most commonly involve transient neuropraxias of the sciatic nerve. These neurologic symptoms present as weakness in the operative extremity with burning pain down the affected leg [6]. Other nerves that can be potentially injured at the time of surgery are the posterior femoral cutaneous nerve and the inferior gluteal nerve. Postoperative infections are a major concern at this site because of the proximity of the surgical field to the genitourinary tract and the rectum [6].

Commonly reported surgical complications after proximal hamstring tendon repair include the following:

- Neurologic injury (neuropraxia)
  - Sciatic nerve
  - Posterior femoral cutaneous nerve
  - Inferior gluteal nerve
- Poor wound healing
- Hematoma/seroma
- Tendon re-rupture
- Sitting or activity-related pain
- Muscle weakness
- Deep vein thrombosis
- Infection
- Ischial tuberosity fracture

Postoperative Rehabilitation

An appropriately guided postoperative rehabilitation program is essential for obtaining ideal outcomes following proximal hamstring repair. The patient is initially placed into a custom-fit hip orthosis at 30–40° of hip flexion and kept touch down weight bearing for 2 weeks [57]. Weight bearing is then advanced to 25 % of full over the following 3 weeks. Passive range of motion of the knee and hip is started after 2 weeks, and active hip range of motion begins after 1 month. Hip flexion is advanced by 10° each week for the first 6 weeks while the patient wears the hip-knee orthosis [55].

Full weight bearing is initiated after 6 weeks, and the hip orthosis is discontinued at that time. Gait training and aquatic therapy are begun at this point with isotonic exercises, core strengthening, and closed chain exercises being introduced between 6 and 8 weeks [6, 55]. Hip range of motion is also advanced at this point with caution taken at full flexion. Dynamic training and isometric strengthening begin at 8 weeks after surgery, and at 10 weeks an isometric strength evaluation is performed with the knee at 60° of flexion [55].

Dry land jogging and sport-specific training begin between 10 and 12 weeks. A fully isokinetic evaluation is recommended at 12 weeks at 60°/s, 120°/s, and 180°/s. These results are compared with the contralateral leg and should be at least 80 % of that of the uninjured limb prior to return to sports [6, 55].

Return to Sport

Return to sport is permitted once the isokinetic testing of the operative limb equals 80 % of the nonoperative limb. This level is typically reached between 6 and 10 months [6, 23, 55, 58]. The percentage of abnormal muscle area and the volume of injury has been correlated most precisely with time to return to sport [30]. Askling et al. prospectively evaluated 18 elite sprinters with clinically diagnosed hamstring injuries and serial MRI evaluations at 10, 21, and 42 days after injury [2]. Those authors found that proximal hamstring injuries demonstrated most prolonged time to return to play [2].

Postoperative Treatment Outcomes

Most series report that return of strength ranges from 60 to 90 % of the contralateral leg, with up to 95 % of patients or more reporting good to excellent subjective results after surgical repair [6, 23, 24, 45, 59–62]. Klingele and Sallay reported that seven of nine athletically active patients who had complete proximal hamstring ruptures returned to their sports activities at an average of 6 months following repair [51]. Sarimo et al. reported on 41 patients with complete proximal hamstring avulsions and found that 20 of 27 recreational athletes returned to their preinjury level of sports activities within 4–10 months [23, 50].

Wood et al. reported on 72 patients who underwent proximal hamstring repairs. In their series 80 % of the patients had returned to their preinjury level of sports by 6-month follow-up postsurgery with mean postoperative isotonic hamstring strength being 84 % of the contralateral limb [33, 63]. Lempainen et al. reported on 47 athletes who had partial tears of the proximal origin of the hamstrings. Forty-two of the 47 were initially treated nonoperatively with unsatisfactory results. Forty-one of those 42 patients returned to their preinjury level of sports activity after an average of 5 months following surgical repair [63].

Regarding patient-reported outcomes, Konan et al. reported on ten semiprofessional or professional athletes with proximal hamstring tears. Their patients described subjectively excellent functional results by 12 months with hamstring peak torque reaching 82.78 % of the contralateral side by 6 months. Additionally, Cohen and Bradley et al. found in a series of 52 patients that 98 % were satisfied with their outcome after surgery. In their study objective measures such as the Lower Extremity Functional Scale and custom Marx score showed a statistical difference between acute and chronic repairs, with acute repairs exhibiting improved outcomes [45].

Future Directions

Tissue Engineering

In recent years, tissue engineering and cell therapy have gained increasing utilization among elite level athletes. Much research regarding its efficacy has been directed toward skeletal muscle and myotendinous units [20, 23]. These branches of regenerative medicine involve stem cells to reconstitute tissue and stimulate healing of muscle [6]. Though further research is necessary to identify the mechanisms of activation of mesenchymal progenitor cells derived from traumatized muscle to promote wound healing after injury, the potential therapeutic effects are broad and likely to remain the topic of discussion and research for some time [64].

Platelet-Rich Plasma

Platelet-rich plasma products are a source of biologically active molecules that have the potential to improve the healing process in soft tissue injuries [65, 66]. The results published by Mejia et al. showed an earlier return to play in National Football League players who were administered autologous conditioned plasma for hamstring injuries. Though its effect and mechanism remain debatable, platelet-rich plasma has been widely described for the management of many musculoskeletal injuries, including hamstring tears, because it has been found to be safe and is relative easy to obtain [6, 65–67].

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6 Biologic Enhancement of Healing in Ham Injuries

Fotios Paul Tjoumakaris, Steven B. Cohen, and James P. Bradley

Introduction

Hamstring injuries are relatively common injuries in sports medicine and may significantly impair peak athletic performance [1, 2]. Perhaps more than the actual injury itself is the risk of reinjury and continued disability throughout an athletic season or even playing career. Risks of reinjury may range from 12 to 31 % with a significant number of games or athletic events missed [3]. These injuries often occur in the setting of sports that require rapid acceleration and are commonly seen in sprinters and skill position players in football (running back, wide receivers). Injury often occurs as a result of an eccentric stretch on the hamstring muscle group and may range from a mild stretch injury to an avulsion from the proximal attachment while the knee is extended and the hip flexed during high-energy activities [2, 4–6]. The treatment for avulsion in the young and athletic population can be viewed as perhaps more straightforward than muscle strain injuries. Often times, avulsion injuries require surgical repair with the attendant postoperative rehabilitation course [7, 8]. Patients in this group tend to fare well and have a high level of return to athletic participation. Less straightforward and perhaps even more challenging is optimizing the treatment for myotendinous strains or muscle belly injuries. It is often this group of patients that continue to be debilitated by their injury throughout the season and may experience recurrence once return to play is achieved.

The myotendinous junction of the hamstring muscle group may experience the highest loads during eccentric muscle contraction and is a common site of injury [9]. Muscle injury is often characterized by damage to the myofibrils with leakage of creatine kinase from the cell cytoplasm. As injury severity progresses, the extracellular matrix and fascia may become damaged resulting in greater inflammation and enzymatic degradation of collagen and proteoglycan [3]. Healing often involves a combination of dense scar formation and fibrosis, with resultant impaired function of the hamstring muscle with a propensity to reinjure through damaged tissue. During this post-injury inflammation and repair process, there is potential to modify or augment

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the biologic response to achieve an improvement in recovery time and quickening the return of peak athletic performance.

Currently, the standard of care for noninsertional hamstring injuries consists of noninvasive modalities that incorporate the principles of rehabilitation (rest, compression, stretching, ice, modalities) with therapeutic agents that can decrease inflammation and pain (NSAIDs, analgesic medication). Once the acute phase of inflammation has passed, the athlete is slowly placed back on a training program for eventual return to play as symptoms allow. Corticosteroid injections placed within the muscle have been utilized as an early treatment strategy as well to hasten recovery and decrease inflammation [10]; however, they carry a risk profile that may include higher risk of reinjury with the possibility of tendon rupture [11]. While this approach may allow athletes to return to play, the results are variable with an unpredictable amount of games missed and the potential for reinjury always looming. For this reason, there has been significant interest in the use of biologic therapies that may optimize the healing process while decreasing the side effect profile of traditional modalities. Perhaps the agent studied the most widely is platelet-rich plasma (PRP) therapy, with other therapies such as transforming growth factor-beta (TGF-β), fibroblast growth factor (FGF), epidermal growth factor (EGDF), platelet-derived growth factor (PDGF), and vascular endothelial growth factor (VEGDF) being less commercially available in current clinical practice. These agents have the capacity to work directly on skeletal muscle to improve the healing and regenerative process by stimulating both myogenesis and neoangiogenesis [12, 13].

The following chapter will outline the current biologic modalities that are available for use and have been investigated to augment the healing response in hamstring muscle injuries. These are often employed as a treatment strategy for noninsertional injuries; however, they can be used in insertional injury treatment as well. The goals of treatment are always the same: to provide an effective healing response that is safe, reduces the risk of reinjury, and can minimize the time missed from athletic competition.

Platelet-Rich Plasma

Background

Platelets are the products of megakaryocytes produced in the bone marrow and typically have a life span of 5–9 days. Initially, it was believed that the only role for platelets was to act as a plug during the initial phase of hemostasis after tissue injury. During activation at sites of tissue injury, platelets release their α-granules. The α-granules contain a number of bioactive proteins that have a role in tissue healing and hemostasis [14]. Platelets begin secreting these proteins 10 min after clotting occurs and will continue to synthesize and secrete additional growth factors for the duration of their life span [15].

Broadly defined, PRP is a sample of autologous blood with concentrations of platelets above baseline values [16]. PRP contains both a high concentration of platelets in addition to clotting factors and secretory proteins. Platelet-rich concentrate (PRC) is an autologous concentration of platelets and growth factors that includes TGF-β, VEGDF, and PDGF. Due to the high concentration of these growth factors, it is believed that PRC can enhance the recruitment and potential differentiation of stem cells, tenocytes, and endothelial cells [17]. The regenerative capability of PRP is dependent upon the concentrations of growth factors and cytokines that are released when the platelets are activated. In addition, it has been shown in a laboratory study that local injections of PRP may have the potential for a systemic ergogenic effect, temporarily increasing serum levels of insulin-like growth factor-1, VEGDF, and basic FGF [18].

Significant variations may exist among commercially available preparations with regard to platelet concentration, leukocyte concentration, growth factors, and cytokine expression (Table 6.1). Some studies have recommended that platelet concentrates should achieve a three- to fivefold increase in platelet concentration over baseline [17]. A higher concentration of platelets in the preparation may not translate to an enhanced healing effect in vivo. A saturation

Table 6.1 Sample of platelet-rich plasma formulations and characterization [19, 53]

Formulation	Type	Volume (mL)	Platelet concentration over plasma	WBC content
Cascade (MTF)	Platelet-rich fibrin	4.5	1.3×–1.7×	Low
ACP (Arthrex)	Platelet-rich plasma	4–7	2×–3×	Low
GPS III (Biomet)	Leukocyte-rich plasma	6	2×–8×	High
Symphony II (DePuy)	Leukocyte-rich plasma	7–10	3×–7×	High

MTF Musculoskeletal Transplant Foundation, *ACP* autologous conditioned platelets

effect has been delineated in which an inhibitory cascade may ensue after a certain threshold of platelets is reached. In addition to platelets and their growth factors, PRP contains other cell types that may have therapeutic effects during clinical application: monocytes and polymorphonuclear neutrophils (PMN). The inclusion of white blood cells in the preparation may be controversial, as some studies have asserted that neutrophils may impede the healing response [19]. Injured collagen, thrombin, or calcium chloride is necessary to activate the platelet concentrate to secrete growth factors.

PRP is typically prepared through a centrifugation or filtration process that separates anticoagulated whole blood into liquid and solid components. A potential disadvantage of centrifugation is that it may cause fragmentation of the platelets that may cause early release of growth factors and cytokines. Newer, cell-sensitive filtration systems are available that have the potential to mitigate this variable in an operating room or clinical setting [20]. There are more than 40 commercial systems available that purport to convert blood into PRP. Final concentrations of all of the aforementioned variables may be secondary to both the system chosen in addition to the inherent variability and technique employed within each system [21, 22]. Patient-specific factors such as age, medical comorbidities, and circulation may also lead to differences in growth factors and platelet concentrate [23]. Current attempts to create classification systems for PRP so that results can be standardized and compared among studies are under way and will be important when comparing the results from different studies [24]. In a recent Level V paper, DeLong and colleagues devised the PAW classification system in an attempt to compare publications based on three variables of PRP: the absolute number of platelets in the preparation, the manner in which platelet activation occurs, and the presence or absence of white blood cells [19]. Platelet concentration is graded on a scale from P1 to P4, with P4 being concentrations greater than 1,250,000 platelets/μL. White blood cell content of the preparation is graded as either A (above baseline values) or B (below/equal to baseline levels). Neutrophils are graded separately in this system to be either α (above baseline) or β (below baseline). Method of activation is categorized as either endogenous or exogenous (x) in the scheme. The authors cite an example of their system by classifying a PRP preparation with 900,000 platelets/μL with a total WBC and neutrophil content above baseline levels as being a P3-Aα. Classification systems such as these are paramount for researchers to standardize their reporting of the preparation used so that reproducibility of results by other investigators can be documented.

Current Clinical Applications

PRP has gained greater acceptance in orthopedic practice and more specifically, sports medicine. Initially, PRP was used clinically in wound healing, dermatology, and oromaxillofacial conditions [15, 17]. It has demonstrated osteogenic properties in preclinical and in vitro studies; however, clinical outcome studies have not been as promising [25]. In the realm of sports medicine, PRP has been studied for potential positive effects in cartilage healing and chronic tendinopathy. TGF-β1, thrombospondin-1, and IGF have all been found within PRP or upregulated after application of PRP, all of which have the capability of promoting joint repair. In a level I randomized study evaluating the efficacy of PRP (WBC filtered) for bilateral knee osteoarthritis, patients treated with PRP were reported to have better outcomes than controls at 6 months [26]. Despite several other level I evidence studies citing the therapeutic benefit of PRP for the treatment of osteoarthritis of the knee, the current recommendation of the American Academy of Orthopaedic Surgeons based on their released Clinical Practice Guideline, however, is that they were "unable to recommend for or against growth factor injections …for patients with symptomatic osteoarthritis of the knee" [27]. While reversing the course of degenerative arthritis of the knee may be a significant feat for an orthobiologic application, tendinopathy offers perhaps a more feasible goal to harness the body's own capability to promote healing where a halted biologic response has occurred. With regard to lateral epicondylitis, it has been demonstrated that PRP formulations containing white blood cells improve patient outcomes when compared with nonoperative treatment or injections of local anesthetic, whole blood, or corticosteroid [28, 29]. The results of PRP treatment for other tendinopathies (Achilles, patellar) have not been as significant as that for lateral epicondylitis; however, a recent investigation by Bouyer demonstrated excellent restoration of function and architecture of the patellar tendon by magnetic resonance imaging (MRI) after three consecutive injections of ultrasound-guided PRP [30–32]. Further study is needed to determine what dosage and frequency of administration may be able to offer patients with these maladies the most therapeutic benefit.

While PRP has the potential to augment a biologic response in the context of nonoperative treatment, it has also been employed as an adjunct treatment for patients undergoing surgery of the anterior cruciate ligament (ACL), rotator cuff tendon, and Achilles tendon. Successful ACL reconstruction is contingent upon graft incorporation into the femoral and tibial bone tunnels through a biologic response. It has been postulated that graft remodeling may be enhanced by PDGF, TGF-β1, and IGF-1. In a recent investigation, the use of PRP-gel was found to significantly affect the maturation of ACL grafts by MRI at 1-year follow-up [33]. In a similar study using semitendinosus grafts in a randomized controlled trial design, similar findings were found at 6 months in the group that was augmented with platelet concentrate [34]. A systematic review of the literature on this topic demonstrated a potential positive effect on ACL surgery by enhancing graft maturation by 20–30 % [35]. For patients undergoing rotator cuff repair, the task of healing is even more daunting as the rotator cuff tendon is often torn in a degenerative mechanism. In a systematic review evaluating the effect of PRP on rotator cuff healing after surgery, it was found that PRP demonstrated no beneficial effect with regard to re-tear rates or clinical outcomes [36]. In one investigation, platelet-rich fibrin matrix therapy was found to negatively affect repair integrity at 3-month follow-up [37]. The results of studies on Achilles tendon repair have been rather equivocal, similar to those findings seen in rotator cuff surgery, and to date no study has demonstrated a decreased risk of re-rupture with biologic augmentation utilizing PRP.

Effects of PRP on Muscle Tissue

While PRP has shown some benefit in the setting of chronic tendon inflammation, it is unclear what effects PRP demonstrates on muscle tissue. A recent investigation evaluated the effects of PRP on myoblasts in culture. This study demonstrated that an early differentiation marker (MyoD) was upregulated after 7 days, indicating a potential biologic effect on muscle tissue [38]. In a muscle injury model, PRP was applied to muscles that were injured in experimental rats. It was found that the muscle tissue treated with PRP demonstrated greater leukocyte infiltration and contralateral muscle also demonstrated an increase in protein expression of the involved leukocytes, indicating a systemic response that magnifies the early inflammatory response after muscle injury [39]. Platelet-rich fibrin matrix has also been shown to improve muscle regeneration, promote neovascularization, and inhibit fibrosis in treated muscle tissue [40]. In a small animal injury model evaluating the effects of PRP on muscle strains, local delivery of PRP into a multiple strain muscle injury demonstrated improvement in recovery time and restoration of full contractility [41]. In an attempt to determine the optimum PRP application for muscle tissue, Mazzocca and colleagues [42] exposed muscle tissue to three different PRP preparations (lower platelet concentration, high platelet and white blood cell concentration, high platelet and low white blood cell concentration). The results of this study demonstrated that myocytes treated with a low platelet preparation demonstrated significantly more proliferation than controls and the other preparations studied. Studies such as these can further define the optimum concentration of platelets required for the specific clinical setting. For example, this same study demonstrated that tenocytes are also positively affected by PRP with a low platelet concentration; however, tenocytes also favorably responded to the high platelet concentrations. There is promise that, in the future, specific preparations for the tissue being treated will be available and may further calibrate the biologic response intended.

Results of PRP for Hamstring Injury

The senior author (JPB) has reported on his experience of autologous conditioned plasma (ACP) injections given within 2 days of acute hamstring injuries in NFL football players [43]. These results demonstrated an earlier return to play of 3 days for grade I injuries and 5 days for grade II injuries. There was a one-game overall difference in return to play and 0 % risk of recurrence of injury in this patient cohort. In another review of 15 patients with 17 proximal hamstring injuries, 12 patients underwent local injection of PRP for insertional injuries that failed conservative treatment. While all the patients in this series returned to their desired activity level, the PRP-treated group demonstrated a significant reduction in visual analog scale scores and Nirschl Pain Phase Scale scores [44]. In a multicenter review of patients receiving ultrasound-guided PRP injections for chronic tendinopathy, 17 patients underwent treatment for a hamstring muscle/tendon injury [45]. The authors of this study demonstrated that greater than 80 % of patients reported complete resolution of their symptoms at final follow-up. While the majority (60 %) of patients only received one injection, a significant number of patients did require three or more injections (10 %) during their treatment course. In a pilot study evaluating the effects of PRP on muscle injuries, Wehling and colleagues [46] demonstrated an improvement in the recovery time of nearly 1 week for treated muscles in addition to accelerated healing on high-resolution (MRI) imaging. In this study, 6 of the 18 patients studied had hamstring muscle strains. To date, no level I studies have been completed that demonstrate efficacy of PRP in the treatment of hamstring muscle injury. Recently, a randomized controlled trial protocol was introduced in an effort to study the effects of PRP on grade II hamstring muscle injury [47]. There is hope that this investigation can more definitively answer the question of whether biologic therapy for hamstring strains improves recovery, reduces the risk of reinjury, and is clinically safe for practice.

Author's Preferred Technique for PRP Administration

Patients who sustain an injury to the hamstring muscle are first graded based on MRI criteria (grades I–III) as previously defined [48]. In this grading system, the score is based on patient age, number of muscles involved, location of injury, presence of insertional damage, percentage of cross-sectional muscle involvement, length of muscle retraction, long axis T2 sagittal plane signal abnormalities, and the presence of chronic changes. Patients are initially rested for 24–48 h to allow for clotting at the site of injury and endogenous platelet activation to occur. After this time, using either ultrasound guidance or fluoroscopy with correlation to MRI, injection of a leukocyte-poor PRP preparation (ACP—Arthrex, Naples, FL) is placed within the zone of injury. Patients then receive routine post-injury care by athletic training staff with standard rehabilitation protocols and minimal stretching. The patient is then seen a week later for a repeat injection at the same site as the prior inoculation.

The patient is then seen a third week for a repeat clinical evaluation. If the patient is still symptomatic at this visit, a third injection is performed. If the patient is asymptomatic at this time, they are released from care. Patients are allowed return to play when they demonstrate near full strength and flexibility, with minimal to no pain at the site of injury.

Growth Factors and Stem Cell Therapy

There are several potential therapies that may enhance the biologic healing for hamstring injuries, although little data exists at this stage. These include stem cells and delivery of specific growth factors, many of which are contained within the α-granules of platelets. Stem cells have the potential to regenerate tissue by direct expression of cell types that enable healing and repair. For example, animal studies have shown that in models of muscle injury, muscle-derived stem cells (MDSCs) improve both muscular structure and muscle regeneration [49, 50]. In vitro tissue engineering allows either stem cells or growth factors to be placed on a scaffold for direct delivery into damaged tissue. The hope is that ultimately, isolated MDSCs could be seeded onto a scaffold carrier and placed within a specific zone of injury, such as a hamstring muscle, providing the necessary biomaterials for complete repair and recovery of injured tissue [51]. While all of the recent advances in laboratory and bench research are promising, no clinical applications of stem cells have been introduced for the repair and healing of hamstring injuries.

Within the α-granules of platelets, many of the growth factors have potential clinical applications in isolation that could be used in the future for a targeted biologic response. TGF-β, FGF, PDGF, EGDF, VEGDF, and IGF-1 have all been isolated from the α-granules of platelets and studied for efficacy in muscle injury and repair. IGF-1 and FGF have been shown to stimulate myoblast proliferation and myoblast fusion [52]. TGF-β has been shown to stimulate mesenchymal cell proliferation and promote extracellular matrix production. PDGF has demonstrated ability to stimulate fibroblast chemotaxis and the mitogenesis of mesenchymal cells. EGF has demonstrated the ability to stimulate fibroblast migration and proliferation, and VEGF has shown efficacy for stimulating myoblast migration. All of these growth factors either in isolation or within a "cocktail" may prove useful in the future for clinical use in targeting damaged muscle. Currently, PRP offers the most promising benefits and has been studied more extensively in a clinical context; however, it may ultimately be proven that some of the factors contained within PRP preparations may be harmful to the healing response and an "ultrafiltrate" of PRP may be more beneficial. With daily advances in this exciting field of study, answers are still forthcoming.

Summary

Returning the athlete to the field of play as safely and effectively as possible has always been the mission of the sports medicine physician. Hamstring injuries are currently a vexing problem for the team physician. While no overt signs of injury are present, muscle damage as documented by MRI and by the clinical symptoms of soreness, fatigue, and pain can severely limit optimal athletic performance. PRP therapy has recently been investigated as it has the potential to harness the body's natural ability to heal muscular injury with a supraphysiologic response. Current clinical studies are promising as they demonstrate improvement in pain and quicker return to play than is seen with traditional therapy techniques. In addition, basic science studies support the use of PRP and other growth factors as they have been shown to have positive effects on the regenerative capability of muscle tissue. Current research is aimed at standardizing nomenclature and classification of PRP preparations in addition to quantifying the effects of specific growth factors contained within the α-granules of platelets. These studies and those that are to be forthcoming in the future will go a long way to improving our standard of care for the treatment of hamstring muscle injuries.

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7 Hamstring Harvest: Rehabilitation and Clinical Outcomes

Kyle Randall, Avijit Sharma, and Robert A. Magnussen

Introduction

The use of the hamstring autograft for anterior cruciate ligament (ACL) reconstruction is widely accepted and becoming more popular both nationally and worldwide (Fig. 7.1). In the United States the percentage of surgeons preferring hamstring autografts for primary ACL reconstruction rose from 12 % in 1999 to 32 % by 2006 [1, 2]. In Canada 73 % of surgeons reported preferring hamstring autografts in 2009, and recent publications indicate up to 63 % of primary ACL reconstruction are performed with hamstring autograft in 57 other countries around the world [3, 4].

Multiple questions about the morbidity of semitendinosus and gracilis tendon harvest have arisen due to their popularity as grafts for numerous reconstructive procedures: Does the harvest of hamstrings put the patient at a greater risk of hamstring strain or pain in the future? Do the hamstring tendons regenerate after harvest? How does hamstring harvest affect knee flexion strength? Does preservation of the gracilis or the use of a contralateral hamstring graft have any effect? These questions have been at the forefront of both surgeons' and patients' minds when considering graft choices. The goal of this chapter is to review what is known about the morbidity of hamstring harvest and factors that affect this morbidity.

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Risk of Subsequent Hamstring Injury

A major concern following hamstring harvest is the risk of subsequent hamstring strain or other injury in the future. Hamstring injuries are common, especially in high-level athletes and those participating in various field sports such as soccer. Such injuries can lead to significant disability and time lost due to injury [5, 6]. One may postulate that harvest of the hamstrings could lead to a change in the overall biomechanics of the patient's lower extremities and potentially place them at increased risk for future hamstring strains. The current evidence in the literature regarding hamstring strains after harvest is limited, although several studies have addressed this subject.

Scranton et al. studied 120 patients at least 2 years following hamstring harvest for ACL reconstruction with a hamstring pain evaluation form. They noted that 22 % of patients had minimal symptoms or a "twinge" of hamstring pain at some point during their post-ACL rehabilitation but that these symptoms did not limit their rehabilitation or return to athletic function [7].

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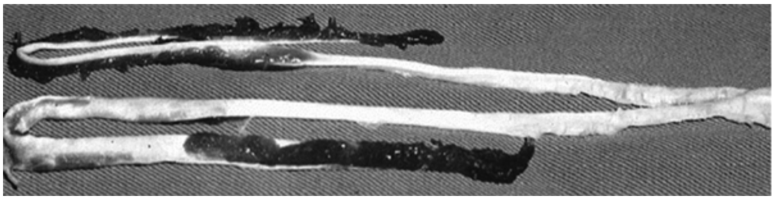

Fig. 7.1 Typical appearance of the semitendinosus (*longer*) and gracilis (*shorter*) tendons after harvest for ACL reconstruction. With kind permission from Springer Science+Business Media: Magnetic Resonance Imaging of the Knee, 1st ed., 2013, [35]

There have been studies linking previous knee injury or ACL reconstruction with increased risk of hamstring injury. Koulouris et al. reported that athletes with a previous ipsilateral ACL reconstruction were at increased risk for hamstring reinjury (66.6 %) compared with athletes without a previous ACL reconstruction (17.1 %) [8]. These findings were similar to those of Verrall et al., who prospectively evaluated athletes on two Australian rules football clubs. When they compared those who sustained hamstring injury during the season with those who did not, they noted the injured athletes were significantly more likely to have had a prior severe knee injury such as an ACL tear [5]. Finally, a systematic review was performed by de Visser et al. to identify risk factors for reinjury following acute hamstring strains. Aside from grade and size of initial injury, the only other variable found to have a significant association with reinjury was a history of previous ACL reconstruction [9].

While three studies described above do demonstrate negative effects of ACL injury of the risk of subsequent hamstring injury and prolonged recovery, it should be noted that none of the studies demonstrated any influence of autograft type (bone patellar tendon bone or hamstrings). Each noted the risk of hamstring injury to be equal between those who were reconstructed with hamstring and bone patellar tendon bone autograft. This finding suggests that ACL injury rather than hamstring harvest is in fact associated with subsequent hamstring problems.

The technique used to harvest the hamstrings has also been hypothesized to affect donor site morbidity. The Push technique uses tendon strippers to push past the myotendinous junction until the tendon comes loose (see Fig. 7.1). The Cut technique involves a device in which a predetermined length of tendon is harvested by using a small blade to cut the tendon near the myotendinous junction. D'Alessandro et al. performed a randomized clinical trial to assess if there was a difference in hamstring pain, muscle strains, and leg flexion strength between these two techniques. While there was no difference found in the strength or the activity level between the two groups as measured by the Cincinnati sports activity ratings scale, the "Cut" group recorded lower average pain on the visual analog scale of 10 mm compared with over 24 mm ($p=0.0398$). There was also a significant difference in the incidence of hamstring strains with 25 % of the "Cut" group reporting at least one strain in the postoperative period compared to 50 % of the "Push" group ($p=0.045$). The authors theorized that tendon regeneration following the "Cut" technique would be more robust than that from a stripped muscle belly and could promote regeneration of a more normal, functional tendon [10], but this finding was not clearly demonstrated.

Overall the evidence is very limited with regard to the relationship between hamstring harvest and subsequent hamstring injury. While the studies demonstrate that having a previous ACL reconstruction puts one at risk for hamstring injury, the relationship appears independent of graft type. More studies are needed to distinguish whether graft harvest or the altered biomechanics of the recovering limb is the primary risk factor for this association.

Effects on Hamstring Strength

Loss of hamstring strength following harvest for ACL reconstruction is a major concern, spawning numerous studies that compare strength between the harvested limb and the contralateral side. In 1997 Simonian and colleagues studied the effect of hamstring harvest of both the semitendinosus and gracilis tendons with a minimum 3-year follow-up [11]. They looked at size of the muscles and extent of retraction on MRI along with dynamometer testing at 90 and 180°/s. The average hamstring strength of the operative limb was 95.3 % of the contralateral side, which they found to not be significant. The MRI findings showed the average semitendinosus and gracilis insertions to be 26.7 and 47.1 mm more proximal on the operative side. The select patients without evidence of semitendinosus tendon remnant at 10 cm above the joint line showed an average of 10.3 % strength deficit compared to the contralateral side.

In 1998 Ohkoshi et al. took the question a step further and looked at not only the peak torque generated by the harvested hamstrings but also their peak torque angle in flexion. Although the overall peak torque values of the operative and nonoperative knee were not significantly different, the peak torque angle decreased significantly, ranging from 11.7° to 15°. This finding shows the effect of the shortening of the muscle unit, with the shift in the peak torque curve to the left toward the earlier angles of flexion. More than 80 % of their patients showed no secondary peak in the latter half of the curve as was seen on the nonoperative side [12]. Tadokoro et al. verified this finding with a 2-year follow-up study in which he measured peak torque in the sitting position at 90° and prone at 90° and 100°. The isometric peak torque was reduced to 86.2 %, 54.6 %, and 49.1 %, respectively, in those three positions [13].

Similarly, Nakamura et al. noted the side to side torque ratio at 90° of flexion was significantly lower (by more than 10 %) than that in the ratio at the peak torque flexion ankle. Their results show that knee flexor strength of the harvested limb is less restored at deeper knee flexion angles than at the angle where peak torque is generated [14].

Previous studies suggest that recruitment of motor units in the quadriceps was hindered bilaterally after ACL reconstruction [15, 16]. A similar effect may be present in the hamstring muscle group. A study by Konishi et al. used MRI to measure muscle volume of the semitendinosus in controls, uninjured limbs of patients having ACL reconstruction, and the injured limb after harvest at time periods of ≤6 and 12 months after surgery [17]. The results of the study indicated that the strength of the injured knee flexors at ≤6 months were significantly lower at both 60 and 180°/s velocities. At 12 months the strength recovered to more than 90 % of the uninjured knee, which suggested slight residual weakness in the injured group, but the significance dissipated. The total volume of hamstrings was also significantly decreased in the injured compared to uninjured limbs. When calculating the muscle torque per unit volume, the results indicated significantly lower peak torques in both injured and uninjured sides at 12 months after surgery compared to controls. Interestingly there was no difference between the injured and non-injured sides. This suggests that there may be bilateral weakness in the hamstrings similar to reports of the quadriceps. The mechanism is still unknown as to the cause of this pattern, but the authors deduced that it was not likely neurological in nature because they did not show a significant difference at ≤6 months of muscle torque per unit volume compared to controls.

The flexion strength of the hamstrings may be correlated to their ability to regenerate. Choi et al. in 2012 evaluated flexion strength and functional performance based on the hamstring tendon regeneration seen on 2-year follow-up MRI. Isokinetic testing and MRI were performed on patients, and they were placed in three groups: both semitendinosus and gracilis regenerated, only one tendon regenerated, and no tendon regeneration. Their results showed significant differences in flexor deficit between the groups in which no tendon regenerated and the groups where at least one tendon regenerated. Functionally there was a significant difference in the carioca test time between those that had no tendons regenerate and those that had both tendons regenerate [18].

It is important to remember that the hamstrings also function as secondary hip extensors and their harvest may have an impact on hip extension and adduction strength. This role could be important for athletes who participate in sports with significant running at high speeds such as soccer, American football, track, and rugby. Hiemstra et al. briefly reported on an outcome analysis in which they compared 15 patients 1 year removed from ACL reconstruction with hamstring autograft to a control group and found that hip adduction strength was diminished significantly by 35.8–43.7 % when compared to BMI normalized controls. In terms of hip extension, the control group had a naturally significant difference in dominant over nondominant limb strength. That natural difference was lost in patients in who the dominant ACL reconstructed. Hip extension in these limbs was diminished to the level of the nondominant side [19]. Goeghegan and colleagues performed a nonrandomized prospective case control comparing hip extension strength following ACL reconstruction with semitendinosus and gracilis harvest versus bone patellar tendon bone harvest. They found a significant difference at the 3-month mark with the hamstring harvest group having weaker extension than the bone patellar tendon bone group. By the 12-month mark; however, the hamstring group had recovered to a level equal to the bone patellar tendon bone group. They concluded therefore hamstring harvest has no detrimental long-term effect on hip extension compared to bone patellar tendon bone graft harvest [20].

Does Preservation of the Gracilis Matter?

Two common four-strand hamstring autografts are the quadrupled semitendinosus graft (4ST) and the doubled semitendinosus and gracilis graft (2ST-2G). Some would suggest that the gracilis plays an important role in reinforcing the semitendinosus muscle in deep knee flexion and that harvesting the gracilis as well puts the patient at a strength disadvantage. The gracilis and semitendinosus also are active in internal tibial torsion, and there is concern that harvesting both leaves the patient without a muscle to be able to compensate for the loss. The counterargument for harvesting both tendons is that the 4ST graft is at times not long enough to support adequate bone tunnel fixation.

Adern and Webster performed a systematic review on the limited number of studies that compared outcomes of 4ST or 2ST-2G grafts in ACL reconstruction [21]. They found seven studies that compared the knee flexion strength in the two groups. All studies had a harvest from the ipsilateral limb. No differences were found between the two groups in the six of the seven studies in isokinetic peak torque at 12 months, although there was a trend in favor of the 4ST graft. One study obtained torques at 70°, 90°, and 110° knee flexion at 60°/s and 180°/s velocities and noted a significant difference at all angles favoring the 4ST group at the 18-month mark [22]. Two studies recorded active knee flexion range of motion with the hip in full extension, and both studies showed a significant deficit in standing knee flexion in the 2ST-2G grafts [14, 23]. The clinical relevance of the prone isometric difference and the standing knee flexion angle remains to be determined. These tests are performed with the hip in full extension and may place the hamstrings at a length disadvantage if there is any shortening of the muscle after harvest. This position is relatively rarely encountered during most sports, and weakness in this position may be clinically important.

Since the review by Adern and Webster was performed, Yosmaoglu et al. evaluated 46 subjects who underwent ACL reconstruction and divided them into 4ST and 2ST-2G groups [24]. They recorded isokinetic quadriceps and hamstring torque, motor coordination, and anterior tibial translation at 12 months after surgery. There were no side to side differences in quadriceps peak torque, tibial translation, or motor coordination found. The only difference found that was significant was in side to side flexor peak torque at 60°/s favoring the 4ST group.

Recently, Barenius and colleagues used subjective scores, function, strength, and tibial rotation measured by gait analysis as variables for evaluating 20 patients who had ACL reconstruction using either 4ST or 2ST-2G grafts [25]. For the tibial torsion portion, they used a three-dimensional motion analysis system and analyzed rotational laxity during stair descent and pivoting activity. All of the outcome measures including tibial torsion showed no significant differences between the two groups.

Overall, while some studies show a trend toward improved deep knee flexion with the 4ST graft, there have not been any other relevant differences in outcome reported based on whether the gracilis is harvested or preserved. Further studies are needed to sort out potential advantages if the 4ST graft, especially in sports such as wrestling and gymnastics that require strength in deep flexion.

Is There an Advantage of Contralateral Harvest?

Yasuda and colleagues reported on contralateral hamstring harvest in a 1995 study in which they wanted to distinguish the morbidity of the semitendinosus and gracilis harvest from that of ACL reconstruction [26]. They randomized 65 patients who underwent ACL reconstruction to an ipsilateral versus contralateral hamstring harvest. They found no difference between the groups with respect to range of motion, laxity, or Cincinnati Knee Rating System scores. The peak torque in the hamstrings was significantly lower in the harvest only side at 9 months compared to those knees that were nonoperative in the ipsilateral harvest group. The ipsilateral harvest knees had significantly lower peak torque than those in the ACL reconstruction but no harvest group, but the difference resolved by 3 months after surgery.

More recently McRae et al. evaluated patients' quality of life measures in a similar study [27]. They prospectively randomized 100 patients undergoing ACL reconstruction into an ipsilateral or a contralateral harvest group with the primary outcome measures being the ACL Quality of Life questionnaire (ACL-QOL), concentric knee flexion and extension strength, International Knee Documentation Committee (IKDC) form, pain, and rate of reruptures. They found no significant differences in ACL-QOL scores, IKDC scores, pain, or reruptures over time. The only significant difference found was between the knees in both harvest and ACL reconstruction and the completely nonoperative knees in regard to flexion and extension strength at 3 months after surgery. This difference resolved by the 6-month mark. Their results fell in line with the previous study, and they concluded that there is no significant difference between harvesting from the ipsilateral or the contralateral limb.

One theoretical advantage of contralateral graft harvest is providing protection to the new graft by keeping the hamstring tendons of the reconstructed knee intact to function normally in dynamically stabilizing the knee. However, recent studies have shown that the rate of rerupture of an ACL graft is 1.5–8 % [28–30], while the rate of contralateral rupture of the ACL is reported between 3 and 7 % [28–30]. This finding casts doubt on that theoretical advantage.

Do Hamstrings Regenerate After Harvest?

We have previously discussed the implications of hamstring harvest on strength and alluded to the relationship between the degree of tendon regeneration and strength, particularly in deep knee flexion. Thus, a key question is: do these tendons regenerate after harvest? The ability of hamstrings to regenerate was first described by Cross et al. in 1992 in a study in which they analyzed four patients after ACL reconstruction. They visually noted the presence of tendon-like structures in the prone position during knee flexion and then confirmed their regeneration with MRI [31]. An example of tendon regeneration can be seen on MRI in Fig. 7.2. Leis et al. evaluated semitendinosus regeneration in a rabbit model in 2003 [32]. They used MRI, gross and histologic pathologic specimens, and biomechanical evaluation at 16 and 28 weeks post-harvesting. They found that all ten rabbits had demonstrated regeneration at 16 and 28 weeks. Biomechanical strength was 23 % of normal tendon at 16 weeks and 62 % at 28 weeks. Histologically, the regenerated tendons at 16 weeks showed wavy, longitudinal, and somewhat organized collagen. At 28 weeks the microscopic evaluation showed well-organized, densely packed, longitudinal large collagen fibrils with mature cross-linking, consistent with tendon healing.

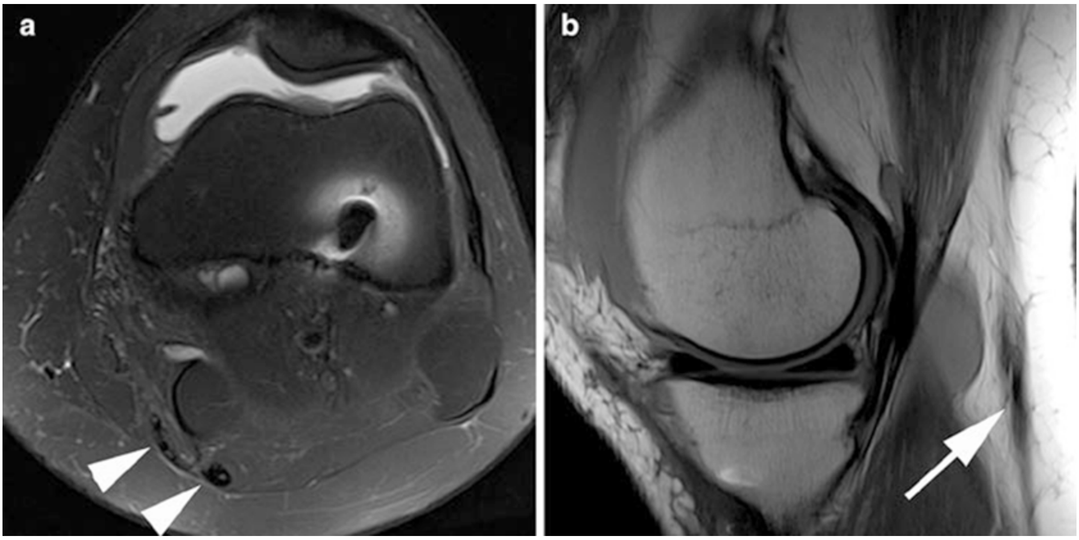

Fig. 7.2 Axial T2 fat-saturated MR image (**a**) in a patient who has undergone harvest of both the gracilis and semitendinosus tendons for ACL reconstruction. The *arrowheads* demonstrate the sites of tendon regeneration. A sagittal proton-density image (**b**) demonstrates that the regenerated tendons are located more posteriorly in the popliteal fossa than normally seen prior to harvest (*arrow*). With kind permission from Springer Science+Business Media: Essential Radiology for Sports Medicine, Robinson P, editor. Postoperative imaging in sports medicine, [36]

In 2005 Nakamaes et al. used 3D computed tomography to examine the regeneration of the semitendinosus tendon after harvest for ACL reconstruction [33]. They examined 29 patients who had a semitendinosus only harvest at 6 and 12 months after surgery and measured the morphology of the new tendons and the proximal shift. They then compared these results to the peak torque ratio at these intervals. Only two of the patients failed to show regeneration of the semitendinosus tendon. Of those that did regenerate, by 12 months, 11 appeared normal, 6 were hypoplastic, and 3 hyperplastic. The average proximal migration of the musculotendinous junction was 7.1 ± 1.9 cm at 12 months. The amount of proximal shift showed significant correlation with decreased peak torque at 6 months, but by 12 months, there was no difference side to side regardless of migration distance. The type of tendon described also did not significantly differ side to side in terms of peak torque. Tadokoro's study looked at patients who had both semitendinosus and gracilis tendons harvested and used MRI to evaluate tendon regeneration. Their results were similar with regard to rate of regeneration (79 %), strength findings, and no correlation with the morphology [13].

A recent study by Jansen et al. found that regeneration of the gracilis occurred in all 22 patients and the semitendinosus regenerated in 14 of the patients prospectively evaluated [34]. They found that the cross-sectional area of the muscle was greater in the cases in which regeneration occurred distal to the joint line ($p = 0.01$). There was no relationship between isokinetic strength and tendon regeneration status. Choi et al. did a similar study but more closely evaluated the relationship between the number of tendons regenerated and isokinetic strength as well as functional performance and its correlation to tendon regeneration [18]. They found that those patients that had no signs on MRI of either tendon regenerating had a significant flexor strength deficit in the seated and prone positions compared to those that had one or both tendons regenerate.

Overall, the current literature tells us that hamstring tendons regenerate in a high proportion of patients. There does seem to be a correlation between tendon regeneration and the resultant strength and diameter of the muscle. The overall functional consequences of a failure of the tendons to regenerate are still to be determined. More studies need to be conducted to determine why some tendons regenerate while some do not.

Summary

Evidence is very limited with regard to the relationship between hamstring harvest and subsequent hamstring injury. Knee flexion strength loss following hamstring harvest is generally between 5 and 15 %, with the greatest deficits noted at greater flexion angles. There is currently little evidence demonstrating improved outcomes with gracilis preservation or contralateral hamstring harvest. There does seem to be a correlation between tendon regeneration and the resultant strength and diameter of the muscle, although the functional consequences of a failure of the tendons to regenerate are poorly defined.

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8 Proximal Quadriceps Injuries in Athletes

Kendra McCamey and Clinton Hartz

Anatomy

The quadriceps femoris is a muscle group made up of four muscles. These muscles are the vastus intermedius, vastus lateralis, vastus medialis, and rectus femoris (Figs. 8.1 and 8.2). The vastus intermedius lies on the front of the femur. Its origin is the proximal 2/3 of the anterolateral femur, lower 1/2 of the linea aspera, upper part of the lateral supracondylar line, and the lateral intermuscular septum [1]. The vastus lateralis and vastus medialis lie in front of the vastus intermedius on the lateral and medial side of the femur, respectively. The origin of the vastus lateralis is the upper part of the intertrochanteric line, anterior and lower borders of the greater trochanter, lateral lip of the gluteal tuberosity, upper half of the linea aspera, lateral intermuscular septum, and tendon of the gluteus maximus [1]. The origin of the vastus medialis is the lower 1/2 of the intertrochanteric line, the medial lip of the linea aspera, upper part of medial supracondylar line, the medial intermuscular septum, and the tendons of the adductor magnus and longus [1]. The most superficial of these muscles is the rectus femoris. The origin of this muscle is typically described as having two proximal heads (tendons). The direct (straight) head originates on the anterior inferior iliac spine and the reflected (indirect) head originates on the groove on the upper rim of the acetabulum [1]. It is reported that there is about a 10–20 % overlap in these proximal tendon fibers [2]. Pasta et al. describe a third head that is a small reflected tendon that attaches to the anterior capsule of the hip joint [3] (Fig. 8.3). Distally all of these muscles combine to form the quadriceps tendon which attaches to the patella, crosses the patella, and inserts on the tibial tuberosity via the patellar tendon.

As stated above, the proximal tendon of the rectus femoris has both superficial and deep components [4]. The direct head forms the superficial anterior fascia that covers the ventral aspect of the proximal 1/3 of the muscle. The tendon of the indirect head travels parallel and deep to the direct head ending in the distal 1/3 of the muscle belly. This terminal extension of the indirect head forms an intramuscular muscle-tendon junction and a "muscle within a muscle" [4, 5] that has been described by Hughes et al. [4] and Hasselman et al. [2]. The rectus femoris muscle is unipennate in its proximal third. The fibers arise from the direct head and travel distally to insert onto the distal tendon. Distal to the direct head, it is a bipennate muscle. Muscle fibers arise from the indirect tendon and extend medially and laterally to insert distally on the tendon of insertion [2, 4].

The quadriceps muscle group is innervated by the femoral nerve, and its blood supply comes

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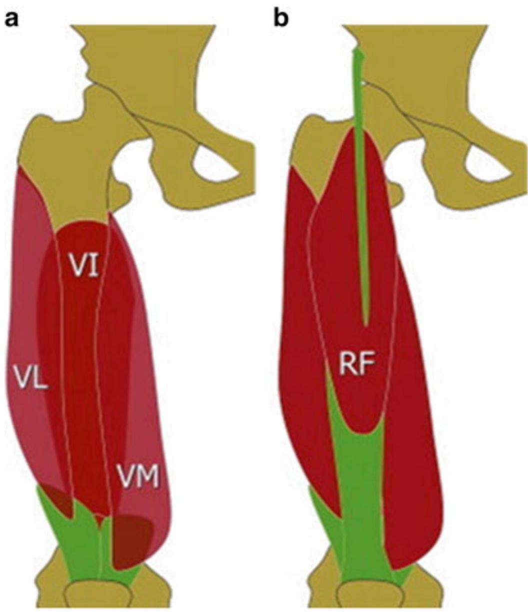

Fig. 8.1 Anatomy of the quadriceps muscle. (**a**) Deep plane, (**b**) superficial plane. *VL* vastus lateralis, *VI* vastus intermedius, *VM* vastus medialis, *RF* rectus femoris. Reproduced from Pasta G, Nanni G, Molini L, Bianchi S. Sonography of the quadriceps muscle: Examination technique, normal anatomy, and traumatic lesions. J Ultrasound. 2010;13:76–84.

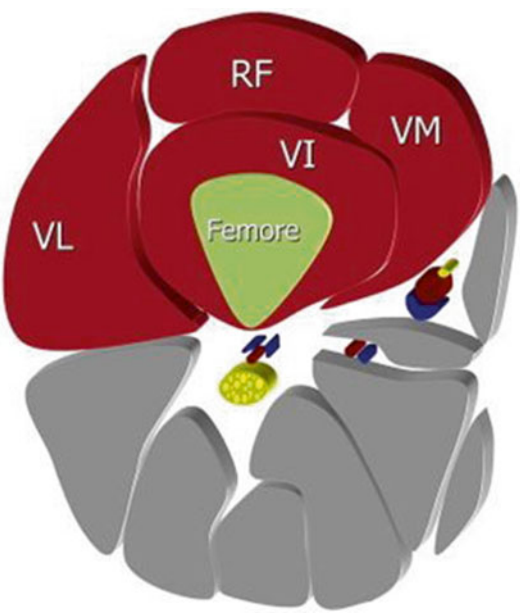

Fig. 8.2 Anatomy of the quadriceps muscle. Axial plane (diagram): *VL* vastus lateralis, *VI* vastus intermedius, *VM* vastus medialis, *RF* rectus femoris. Reproduced from Pasta G, Nanni G, Molini L, Bianchi S. Sonography of the quadriceps muscle: Examination technique, normal anatomy, and traumatic lesions. J Ultrasound. 2010;13:76–84.

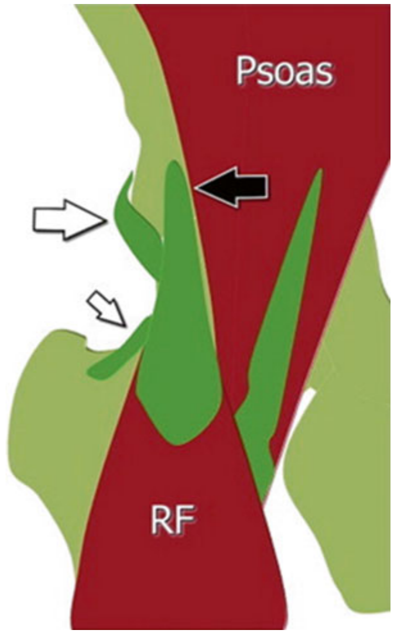

Fig. 8.3 Anatomy of the proximal rectus femoris. *RF* rectus femoris, *black arrow* = direct tendon and its insertion on the anteroinferior iliac spine; *white arrow* = indirect tendon and its insertion on the lateral aspect of the acetabular rim; *small white arrow* = reflected tendon and its insertion on the anterior articular plane. Reproduced from Pasta G, Nanni G, Molini L, Bianchi S. Sonography of the quadriceps muscle: Examination technique, normal anatomy, and traumatic lesions. J Ultrasound. 2010;13:76–84.

from the femoral artery. The action of the muscle group is to extend the leg at the knee. The rectus femoris is the only one of these muscles that crosses two joints, and it also flexes the pelvis on the femur and stabilizes the pelvis during weight bearing [5]. Gait analysis has shown that during the heel strike of running, the action of the quadriceps is to decelerate knee flexion [4].

Quadriceps Strains

Quadriceps strains are common in sports that require a lot of eccentric contraction such as soccer, track and field, basketball, rugby, and football [2–6]. Activities that require eccentric contraction of the quadriceps include jumping, sprinting, and kicking [2–6]. Three large prospective studies of quadriceps muscle injury did not find any association between a person's age and muscle injury [5]. Previous injury to the quadriceps muscle and recent hamstring strain increase the risk of quadriceps strain [5, 7]. Leg dominance has also been shown to be a risk factor for quadriceps muscle strain with the dominant leg being injured more than the nondominant leg [5]. A dry playing surface and ground firmness have also been shown to be risk factors for quadriceps muscle strains [5, 7]. Other proposed risk factors for quadriceps as well as other muscle strains include low muscle strength, muscle fatigue, age, lack of warm-up, muscle temperature, and poor flexibility [6, 7].

Medications that predispose to quadriceps tendon tears include anabolic steroids, statins, locally injected corticosteroids, and prolonged use of systemic corticosteroids; however, many of the studies done on quadriceps tendon tears are focused on the distal, not proximal, tendon injury [8]. Fluoroquinolones and androstenediol supplements have been associated with ruptures in other tendons [8]. Systemic diseases that can predispose to ruptures include renal disease, diabetes, hyperparathyroidism, rheumatoid arthritis, systemic lupus erythematosus, gout, obesity, and infection [8].

The rectus femoris is the muscle most commonly injured in this muscle group [4–7]. Sixty percent of rectus femoris strains occur in the proximal 1/3 of the muscle [3]. Factors that are thought to contribute to rectus femoris strains are the high percentage of type II muscle fibers (approximately 65 %) that the muscle contains [2, 4–6], the fact that it crosses two joints, its eccentric contraction as it decelerates the hip and knee, and its complex musculotendinous architecture (the "muscle within a muscle," as described above) [2, 6]. Injuries of the vastus muscles are typically due to extrinsic factors such as being struck by another player or by an object, and they are less likely to be a result of the intrinsic factor of eccentric loading as are rectus femoris strains [3].

Athletes who sustain an acute quadriceps strain typically notice a sharp pain in their quadriceps associated with a loss of function of the muscle. They often point to the area of the pain in their distal quadriceps, but several studies have shown that quadriceps strains commonly occur at the mid to proximal portions of the rectus femoris [6]. Many times athletes will be able to continue to play, and the pain will intensify later in the day [6].

Strain of the quadriceps may be associated with a bulge or defect in the muscle belly. Bruising may not occur until 24 h after the injury. Pain is often felt by the patient with resisted active muscle activation, passive stretching, and direct palpation of the muscle [6]. In a recent study by Cross et al. [7], it was found that the site of maximal tenderness was often 3 cm or more away from the site of maximal strain on MRI. They also found that tenderness over the rectus femoris didn't always mean that the injury was in the rectus femoris [7].

The treatment of muscle strains to the quadriceps muscles is not unlike strain of any other muscle. There is little scientific evidence for the majority of treatment protocols [6]. Within 24–72 h after a muscle strain, the treatment focuses on minimizing bleeding into the muscle, and hence avoiding further complications, with rest, ice, compression, and elevation (RICE) [6]. A US Naval Academy study showed that immobilization with the knee at 120° in the first 24 h was associated with a return to activity in an average of 3.5 days [9]. A review by Bleakley et al. [10] did not show that the use of ice facilitated faster healing and return to sport; however, they did comment that there are not many high-quality studies evaluating this and more quality research needs to be done. Ice can decrease the pain associated with a muscle injury [6, 10]. If the athlete has a lot of pain, crutches may be needed to help with ambulation immediately after the injury [6]. NSAIDs may be used for a short period (3–7 days), but corticosteroids should be avoided due to possible delayed healing and reduced strength of the muscle [6, 11]. After the first 3–5 days, active rehabilitation is started. Prolonged immobilization has been shown to be associated with longer disability [9]. Rehabilitation includes stretching, strengthening, and range of motion, aerobic fitness, proprioception, and functional training [6]. The intensity of the rehabilitation should be done to the level of patient discomfort but not to pain. Rehabilitation should also be done within a pain-free range of motion [6, 9].

Table 8.1 Grading for quadriceps strains[a]

Grade	Pain	Strength	Physical exam
1	Mild	No or little loss of strength	No palpable muscle defect
2	Moderate	Moderate loss of strength	Possible small palpable muscle defect
3	Severe	Near to complete loss of strength	Palpable muscle defect

[a]With kind permission from Springer Science+Business Media: Current Reviews in Musculoskeletal Medicine, Diagnosis and management of quadriceps strains and contusions, 3, 2010, Joel M. Kary

Grading of quadriceps muscle strains is not much different than any muscle strain (Table 8.1). The severity (grade) of a muscle strain has been defined in many ways. They are typically divided into three grades. A grade 1 strain involves disruption of a few of the muscle fibers within a muscle fascia [3]. Grade 1 strains are also associated with no or minimal loss of strength and no palpable muscle defect [6]. In a grade 2 strain, the surface of the damaged fascia represents less than 3/4 of the total section of the muscle [3]. There is a moderate loss of strength and there may be a small palpable muscle defect in grade 2 strains [6]. In a grade 3 strain, the surface of the rupture extends to more than 3/4 of the total section and may extend to the entire muscle belly resulting in a complete rupture [3]. There is significant or even complete loss of strength in grade 2 strains and there is usually a palpable mass [3]. In adults, muscle strain injury is almost always located at the musculotendinous junction [6].

The rectus femoris is the muscle of the quadriceps muscle group that is most commonly strained [4–7]. With grade 1 proximal strain, there is hemorrhagic infiltrate around the muscle tissue where it attaches to the central tendon. On ultrasound this will appear hyperechoic. Grade 2 lesions show partial rupture of the muscle fibers and a fluid collection (hematoma) around the central tendon. The hematoma will appear as a hypoechoic area on ultrasound. The muscle tissue around the central tendon will also become infiltrated with blood [4]. This will cause enlargement of the muscle belly. There is a complete disruption of the fibers from the central tendon in grade 3 strains, and the muscle bellies may retract. Acutely there will be a hematoma formation around this area, but chronically, healing may result in fibrosis resulting in local retraction of the muscle fibers. On ultrasound, this will appear as hyperechoic areas within the muscle with surrounding muscle retraction [3].

Cross et al. found that the prognosis of acute quadriceps strains was significantly dependent on both the site and size of the injury. Cross-sectional area percentage and length were independently predictive of prognosis [7]. Injuries to the central tendon of the rectus femoris have the least favorable prognosis [7]. In a 3-year causal comparative study by Cross et al. in 40 Australian Rules football players, 25 clinical quadriceps strains were recorded, and none of these were the injuries that have been classically described in literature as the grade 3 complete disruption of the distal rectus femoris. Cross et al. suggest that distal quadriceps strains may not be as common as previously thought. In Cross's study, all 25 athletes who had a muscle strain complained of pain in the midline of the anterior thigh despite seven of the injuries being due to a vastus muscle and three of the injuries having no MRI findings of strain. Also, the site of maximal tenderness was often 3 cm or more away from the site of strain on MRI [7].

Hughes et al. coined the term "bull's-eye" lesion to describe a muscle strain injury associated with enhanced signal around the central tendon on T1-weighted MRI images after IV gadolinium [4, 7]. This high signal is associated with increased vascularity due to chronic inflammation and vascular infiltration of a fibrous scar [4]. This is an incomplete intrasubstance tear occurring at the muscle-tendon junction formed by the deep tendon of the indirect head of the muscle and those muscle fibers taking their origin from this tendon to insert distally into the quadriceps tendon [4]. Each of the injuries in Hughes' study had presented for medical care at least 4 weeks after injury and as long as 156 weeks after injury and are considered more chronic injuries [4]. Cross et al. did a study that included patients who presented within 24–72 h of injury, and they found increased signal, best seen on axial T2 images, about the central tendon. They hypothesize this signal is from edema, hemorrhage, and muscle debris. Cross et al. termed these lesions as "acute bull's-eye" lesions.

In Cross's study on these acute quadriceps strains, the longest return interval was 43 days with an average of 26.9 days for central tendon injuries. Injuries to the rectus femoris that were not around the central tendon had significantly less recovery time [7]. Recovery time was 4.4 days for vastus cases, 9.2 for peripheral rectus injuries, and 5.7 days for MRI negative cases compared to the 26.9 days for rectus central tendon injuries [7].

The longer recovery time seen in athletes with injuries about the central tendon is thought to be due to the shearing forces created because the direct and indirect tendons begin to act independently after this injury [4, 7]. For more chronic injuries, this shearing force is also suspected to be the cause of chronic pain [4, 7]. Hughes et al. explain the chronic pain and dysfunction associated with rectus femoris strains as the indirect (central tendon) and direct heads of the muscles act independent of one another and create shearing phenomena within the muscle [7].

Since injuries around the central tendon of the rectus femoris have been associated with longer recovery times, knowing exactly where the muscle strain injury is located can help determine prognosis for the patient. El-Noueam et al. recommend for those injuries that present within 48 h and where nothing is seen on T2 or STIR weighted images, IV gadolinium should be considered but that it is not used on all injuries [7, 12]. Cross et al. also do not recommend using gadolinium as they feel the risks outweigh the benefits. In Cross' study, the MRI negative strains had an average recovery time of 5.7 days. Since central tendon injuries take longer to heal, they state that this suggests these strains, and thus the "red flag" strains, were not missed [7]. For professional athletes and other high-level athletes, prognosis and return to play often are needed to know in a timely manner, so early MRI with gadolinium can be considered to help with this information.

Quadriceps Contusions

Quadriceps contusions in athletes are a very common injury. Besides strains, traumatic contusions are the most frequent quadriceps muscle injury [6, 13]. Symptoms of a contusion are usually nonspecific. Athletes with a quadriceps contusion have pain with active and passive range of motion with associated limited range of motion [6, 13]. The injury usually occurs from a direct blow to the anterior or lateral aspect of the thigh. Among all of the quadriceps muscles, the rectus femoris is the most susceptible to contusion because of its superficial location [14]. The usual mechanism of injury is from a direct blow to the anterior upper leg leading to disruption or rupture of the type II muscle fibers at or directly adjacent to the area of impact [6, 13–15]. The rupture will typically lead to the development of an intramuscular hematoma causing pain and loss of motion [6]. However, due to the large potential space, excessive hematoma formation can occur in the area of the quadriceps and lateral thigh [13]. In addition, there are varying degrees of muscle injury depending on amount of energy that is absorbed by the traumatic event [6, 15, 16]. As seen in Table 8.2, quadriceps contusions can be classified into mild, moderate, or severe [6].

The diagnosis of quadriceps contusions is mostly a clinical diagnosis through an accurate history and physical exam and usually does not require any form of imaging. Sometimes an athlete will present with vague anterior thigh pain without any mechanism of injury. On these occasions, radiograph, ultrasound, and MRI can be useful to help make a diagnosis [3, 6]. Ultrasound can be used to detect a localized hematoma formation, and real-time imaging can be used for needle aspiration if needed [3, 6]. In addition, if

Table 8.2 Quadriceps contusions classification[a]

Pain	Active knee flexion (°)	Gait
Mild	>90	Normal
Moderate	45–90	Antalgic
Severe	<45	Severely antalgic

[a]Adapted from [20] and [6]

bony involvement is suspected, radiographs can be useful. Radiographs can also help identify heterotopic bone formation known as myositis ossificans, a possible complication of severe contusions [6, 17].

The main treatment for quadriceps contusions is very similar to quadriceps strains. The knee should be passively placed in 120° of flexion causing as little pain as possible, and it should be held in that position for 24 h with a compression wrap or bracing [6, 15, 16, 18, 19]. This will help decrease hematoma formation [6] and likely shorten the time to return to unrestricted athletic activities [19]. In addition to flexion and compression, cryotherapy should be initiated as this acute phase treatment has been proven in several military studies [6, 19–21] to significantly attenuate hematoma size and regional inflammation [22, 23]. After the initial 24 h acute phase, the brace or compression wrap can be removed with the initiation of pain-free active range of motion exercises at the knee with associated stretching and isometric quadriceps strengthening [6, 19]. Once the athlete is pain-free and is able to obtain at least 120° of flexion, he/she can start functional rehabilitation. The use of nonsteroidal anti-inflammatory medications (NSAIDs) has been shown to be useful in the first 48–72 h to decrease pain [6, 11]. However, the long-term effect on muscle healing is unknown, and they may have a negative effect on muscle healing [11]. There has been some thought that the use of NSAIDs may prevent myositis ossificans based on a study showing a decrease in heterotopic bone formation after total hip replacement in those given indomethacin for 7 days [24]. The use of corticosteroids in contusion injuries have been shown to delay healing because it slows the clearance of debris at the injury site which prolongs regeneration of muscle and the recovery of muscle strength [25].

Myositis Ossificans

Myositis ossificans is the development of bony growth within the muscle after a contusion or strain. There has been a 9–17 % incidence of myositis ossificans after a contusion depending on the severity of the contusion with about a 4 % occurrence for mild contusions increasing to 18 % in severe contusions [6, 25, 26]. In addition, myositis ossificans should be suspected in athletes who have increased symptoms 2–3 weeks after a traumatic injury to the quadriceps with associated induration and loss of range of motion over the muscle [6, 25]. When this occurs, imaging should be obtained with radiographs or ultrasonography. Early radiographs will show a soft tissue mass that may be accompanied by faint periosteal bone formation. This can occur in 7–14 days after injury [6, 25, 26]. As the lesion matures, the radiographic findings will evolve and include more mineralization around the periphery of the mass with the central zone being more radiolucent and the development of an "eggshell" appearance. This typically occurs at about 10 weeks or after the initial injury [25]. At 4–6 months, the lesion will look more like lamellar bone and may begin to show signs of absorption [25]. With ultrasound, any bony formation will appear hyperechoic, and the ultrasound waves will not be able to penetrate through the bone. With MRI, images soon after injury are not well defined. The findings of myositis ossificans will be isointense to normal muscle on T1-weighted images and heterogeneous to normal muscle on T2-weighted images. There is also usually a large area of associated edema leading to concern for a neoplasm [25, 27]. However, over time as these lesions mature, the findings on MRI become better defined with fat signal intensity from ossification on both T1- and T2-weighted images along with little or no edema [25, 27].

Treatment for myositis ossificans starts with close observation, stretching, and range of motion exercises. Recent evidence suggests that extracorporeal shock wave therapy may help treat this problem [28]. Before any surgical treatment should be considered, the lesion needs to mature, usually within 6 months to 1 year, and no longer show increased uptake on a bone scan [25, 27]. Early excision can result in local recurrence, and this recurrence can be more severe than the original problem [25, 26]. Unfortunately, many cases of myositis ossificans do not resolve with conservative management and require surgical intervention.

Athletes can participate with myositis ossificans, but they may have restricted range of motion with occasional exacerbations of pain and swelling [9, 13, 25, 26].

Compartment Syndrome

Another complication of quadriceps contusions is anterior compartment syndrome of the thigh. A high index of suspicion for compartment syndrome is needed when a quadriceps contusion occurs as the symptoms of compartment syndrome can be variable and vague [25, 29]. The majority of clinicians will refer athletes for surgical intervention and fasciotomy with compartment pressures higher than 30 mmHg [25, 29], although the absolute pressure threshold remains to be established for the compartment syndrome of the anterior thigh [30]. Some studies demonstrate that pressures greater than 70 mmHg require expedited surgical decompression to avoid complications [30]. In addition, compartment syndrome with femur fracture is treated differently than without femur fracture. Patients with a pressure less than 30 mmHg, with lower injury severity scores, and without femur fracture did better if they developed anterior compartment syndrome of thigh than those with higher pressures, higher injury severity scores, and with a femur fracture [25, 30]. Some cases of compartment syndrome have been reported by Robinson and colleagues to have full recovery and return to activity with conservative treatment only. They postulated this may be due to the large volume of the quadriceps muscle, the relatively elastic fascia around the muscle, and, potentially the most significant reason, the direct proximal connection to the hip musculature allowing for extravasation of fluid out of the compartment [25, 29].

Summary

Proximal quadriceps injuries are common in athletes. They can easily be treated conservatively with cryotherapy, anti-inflammatories, stretching, and therapy as needed. However, with prolonged symptoms and lack of improvement, these injuries may require imaging and, for some of the complications of proximal quadriceps injuries, more aggressive treatment including surgical intervention.

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9 Contusions, Myositis Ossificans, and Compartment Syndrome of the Thigh

Peter Hoth and Annunziato Amendola

Contusions

Contusions of the thigh are a frequent thigh injury in athletics, second only to quadriceps strains [1]. They are the result of a direct traumatic force or compressive injury to the quadriceps. It is particularly susceptible to contusion injury due to the approximation of the quadriceps along the femur for nearly its entire length. Unlike the more common quadriceps strain, contusion causes more direct muscle fiber damage. This damage occurs either directly in the area of injury or in the immediate surrounding areas [2]. Contusions are therefore more likely to form hematomas when compared to muscular strains. Contusions are more common in sports without protective padding of the thigh and upper leg, such as soccer, rugby, or martial arts, but can occur in nearly any sport or athletic endeavor [3]. There has been some limited evidence that thigh protectors do provide some degree of protection from hematoma formation after blunt traumatic injury to the quadriceps [4]. The duration of disability due to quadriceps contusions is quite variable and in the literature ranges from 3 to 180 days [3, 5, 6].

Contracted muscles are better at absorbing force and thus lead to less severe injury. Beiner et al. developed an animal model to compare contusion forces of contracted versus noncontracted, as well as constrained versus non-constrained muscles, and were able to suggest a better resiliency to injury of contracted muscle as well as non-constrained muscle [7].

The diagnosis of contusion is largely a clinical diagnosis, usually with a known history of direct trauma to the affected area. In contrast, muscle strains will not have clear history of direct trauma. Common mechanisms of injury include a knee, helmet, or shoulder to the area, but may also include a kick, the ground, or other equipment [3]. Athletes will typically present with symptoms of pain, swelling, decreased range of motion, as well as impaired performance. Symptoms can have a fairly sudden onset with need for immediate removal from participation or game play, or there may be some delay as in the absence of prompt treatment symptoms are likely to worsen overnight after the injury with further limitation of function, increased pain and swelling, and decreased range of motion.

Physical exam should consist of the standard components of inspection, palpation, range of motion testing, and strength testing. Inspection should evaluate for any gross deformity, swelling compared to contralateral side, erythema, or

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ecchymosis. Palpation along the length of the affected muscle should be used to localize the injury and evaluate for any muscular defects, masses, or potential hematoma formation. Hematomas are usually identifiable within a few hours of injury. As the quadriceps crosses both the hip and knee, full range of motion testing should be done at both joints and compared to the unaffected side for any range of motion deficits.

One of the main concerns with contusion is the determination of the severity of injury, as there can be quite a degree of variability of the severity of injury and time to recovery. The original West Point study looked at 65 injured athletes with quadriceps contusion and found the number of days of disability ranged from 28 to 180 days [5].

Classifications systems have been developed to help determine the severity and thus guide treatment and prognosis. One such classification is based solely on clinical symptoms [3, 5]: mild (knee flexion >90, normal gait), moderate (knee flexion 45–90, antalgic gait), and severe (knee flexion <45, severely antalgic gait).

Compared to muscular strains, contusion injury is more likely to muscular hemorrhage, and subsequent hematoma formation, with overall less fiber disruption. The natural history of contusion shows intramuscular hemorrhage develops quickly, within the first 24 h. Subsequently there is a marked inflammatory response, which can include fiber necrosis, capillary ingrowth, and a proliferation of disorganized fibroblasts [8]. This inflammatory response usually resolves within 1–2 weeks.

Imaging

In the past imaging of thigh contusions was usually unnecessary as quadriceps contusion is largely a clinical diagnosis [9]. Plain radiographs were useful in evaluating for bony injury; however, underlying femur fracture from thigh contusions is a rare occurrence. If further imaging is needed, either musculoskeletal ultrasound (US) or magnetic resonance imaging (MRI) is useful for assessing thigh contusions, as they can clarify the location and extent of the lesion and can be useful in treatment planning [10]. Increasingly, musculoskeletal US has become more widely available and is able to evaluate for muscular edema, fiber disruption, or for more localized hematoma formation.

Ultrasound provides the benefit of dynamic, real-time assessment of muscular function as well as determining the size of the hematoma, if present. In addition if aspiration is a desired option, US guidance is very helpful. Ultrasonography will initially show increased reflectivity secondary to the interstitial bleeding. Very acutely the only change may be an increase in muscle size compared to the unaffected side. Within the first 48 h, ultrasound will show a contusion as ill defined with irregular margins and echogenic swelling. At 48–72 h as the hematoma starts to organize, ultrasound images will show a more well-defined hematoma with a central hypoechoic area and hyperechoic margins. Ultrasound also provides the benefit of US-guided intervention, such as hematoma aspiration, as well as serial examinations to evaluate for hematoma resolution [11]. In recent years US has become more widely available and remains cost-effective, especially when compared to other modalities, such as MRI. It is also well tolerated, noninvasive, and has relatively few, if any, contraindications [12].

MRI provides the benefit of offering improved soft tissue contrast. It can also be useful to evaluate for underlying bony contusion, degree of muscular edema associated with the contusion as well as evaluate for more subtle-type avulsion injuries. In regard to quadriceps contusions, MR imaging shows increased cross-sectional area of the affected muscles, but does not show frank muscle fiber disruption [13]. MRI is beneficial in differentiating between the edema and hemorrhage, which usually appear as a diffusely increased signal intensity on fat-saturated T2 images, and hematomas which cause a heterogeneously high signal intensity at the site of injury [14].

One challenge with MRI is that compared to ultrasound, the healing of the tissues surrounding the hematoma can lead to a more confusing picture. As the hematoma is degraded and resorbed, the varying level of hemoglobin products can lead to a more mixed picture of the area surrounding the lesion, sometimes falsely leading to the suggestion of a more complex mass on MRI.

Treatment

Treatment of contusions has generally been grouped into three categories. Initially the goals are to limit pain and help minimize the degree of hematoma formation. This has been accomplished through a variety of methods, including rest, compression, elevation, and application of ice packs. There have also been recommendations to treat acute injuries more aggressively with compression and knee flexion at 120° either in a hinged knee brace or other elastic support for the first 24 h following injury to help limit hematoma formation. This latter approach has been accomplished through inpatient hospitalization or bed rest at home; however, adherence to this treatment can be challenging and it can lead to increased pain or discomfort over the first 24 h of treatment. Cadets at West Point have been treated with this and have had excellent outcomes with limited to no long-term complications from their thigh contusions [3].

There has been debate more recently regarding whether initial management should involve immobilization versus early mobilization. Immobilization, even for brief periods, can lead to muscular atrophy, joint stiffness, and potentially myositis ossificans [1]. More recent case reports of treatment of professional athletes with severe quadriceps contusions treated with rest, elevation, and early mobilization showed full recovery without immobilization or operative intervention. Interestingly, these athletes also had serial MRI scans that showed that the MRI findings of quadriceps contusion lingered much past their functional ability to return to play [15].

Ryan et al. proposed an excellent three-phase guideline for outpatient treatment of quadriceps contusions. Phase I was meant to limit hemorrhage and consisted of restricted weight bearing, ice, ice massage, compression, flexion, and isometric quadriceps exercises while remaining in flexion. Progression to Phase II started when comfortable and pain-free at rest. Phase II focused on returning pain-free range of motion through ice, active and passive range of motion exercises, isometric strengthening, and removal of compression when thigh circumference returned to the same as the contralateral side. Phase III was started after swelling had resolved and patient had greater than 120° of active knee motion. Phase III consisted of functional rehabilitation done in a pain-free manner [3].

Complications

Three main complications can complicate the natural course and recovery from quadriceps contusions. These include myositis ossificans (MO), compartment syndrome, and Morel-Lavallee lesion, with myositis ossificans being the most common complication, present in 9–20 % of quadriceps contusions [3, 5]. MO is secondary to the formation of heterotopic bone within injured muscle. The pathophysiology of MO remains poorly understood, but it is generally accepted that muscular injury sufficient to cause proliferative repair and macrophage recruitment is necessary to trigger MO. Risk factors for its onset of MO have been set forward by Ryan et al. and include knee flexion less than 120° at time of injury, injury during football, prior quadriceps injury, treatment delay greater than 3 days, and ipsilateral knee effusion [3]. The development of MO was most commonly seen in adults aged 30–40, with a slight male predominance [16]. Clinically, myositis should be considered if pain and swelling continue to increase for the 2–3 weeks following trauma [17]. Symptoms of MO include persistent, prolonged pain at the site of injury, decreased range of motion, tenderness, muscular stiffness, and palpable abnormalities [18]. Figures 9.1, 9.2, and 9.3 show a 22-year-old collegiate, division one, starting wide receiver

Fig. 9.1 Quadriceps relaxed

Fig. 9.2 Quadriceps contracted

Fig. 9.3 Quadriceps anterior

Fig. 9.4 Myositis ossificans: anterior posterior radiograph

Fig. 9.5 Myositis ossificans: lateral radiograph

with a history of remote quad injury. He was treated nonoperatively and returned to play without any deficits.

Imaging is needed to help confirm the presence of MO. Modalities can include plain radiography, ultrasound, or MRI. Plain radiographs can start to show changes of faint periosteal bone reaction as early as 7–10 days after injury but usually take 3 weeks or longer to become visible. The more characteristic findings of a peripheral rim of calcification will begin to be visible as early as 6–8 weeks after injury and will progress over a few months to appear more like mature, lamellar bone [17]. Figures 9.4 and 9.5 show radiographs from a collegiate baseball player who presented with mild aching thigh pain 1 year after a quadriceps contusion. He was diagnosed with MO, treated with physical therapy, and was able to return to full participation without deficit.

Musculoskeletal ultrasound is beneficial for imagining of MO as the calcification will appear as an acoustic shadowing earlier than expected changes on plain radiographs [19]. The main caution is that early changes can appear similar to sarcoma. Typically the changes of MO are more rapidly progressive than a slow growing sarcoma, but serial imaging is needed to help confirm the diagnosis. As MO progresses, ultrasound will show central decreased echogenicity and occasionally an outer lamellar hyperechoic rim [20]. As peripheral ossification ensues and the lesion matures, acoustic shadowing will become apparent.

MRI of MO can also be useful. Initially the imaging shows an ill-defined mass with surrounding edema, which like ultrasound can also have the appearance of a sarcoma. As the lesion matures it will more clearly appear ossified without surrounding edema.

Treatment for MO is mostly close observation. Initially rest, ice, compression, and elevation are generally the treatments of choice, followed by physical therapy and rehabilitation. There is some mixed belief regarding nonsteroidal anti-inflammatory drug (NSAID) use in the acute setting. Some have recommended NSAIDs by extrapolating the data supporting the use of indomethacin or naproxen to prevent heterotopic bone formation following hip replacement surgery [21]. NSAIDs may be helpful in the short term to prevent MO from developing initially, but overall evidence for NSAIDs and corticosteroids shows impaired healing muscle response that could potentially interfere with normal muscular healing. Given the anticoagulant properties, it may be that NSAIDs can also increase the degree of hematoma formation. Therefore, some authors suggest avoidance of NSAIDs for 48–72 h, to avoid hematoma formation, followed by regular use of indomethacin or naproxen to help prevent myositis ossificans [22].

A few case reports and one case series have evaluated the potential for extracorporeal shockwave therapy (ESWT) to benefit in the treatment of MO. Buselli et al. demonstrated that three treatments with ESWT every other week for a duration of 3 weeks showed improvement in range of motion and pain within 48 h of the first treatment. The majority of athletes were able to resume full participation within an average of 11 weeks. Despite decreased pain and improved range of motion, Buselli's study was unable to show a decrease in the size of the ossification with ESWT treatment [23]. Buselli's group also used an intensive rehabilitation program with physical therapy visits six times per week, 80 min at a time [24].

Others have suggested, with little evidence, the use of platelet-rich plasma injections into the area of myositis early in the process to help prevent the overall severity and degree of MO.

Surgical excision, if needed, should not be performed until the ectopic bone has fully matured which may not occur until 12–14 months after the initial injury. King proposes surgical intervention when a mechanical block persists after all of the clinical signs of pain, inflammation, tenderness, and swelling have resolved [25].

Compartment Syndrome

Compartment syndrome of the thigh is a condition more commonly associated with a greater severity of injury, such as underlying femoral fracture. However, it can also be seen from a direct blow to the anterior thigh (in sports such as soccer, rugby, football, and martial arts) [26]. The inexperienced clinician may be led to the precocious diagnosis of compartment syndrome in the first 24 h following a thigh contusion because of the acute, severe pain and swelling. It is imperative in these cases to examine and reexamine the patient in the first 24 h.

The increasing pressure is secondary to vascular trauma leading to bleeding and hematoma formation but can also be seen due to increased capillary permeability with third spacing of fluid within the compartment. Therefore, as noted above, minimizing the swelling after the injury is of primary importance by reducing activity, compression dressings, and icing before beginning more aggressive rehabilitation.

The natural course of compartment syndrome involves increasing the pressures with any of the three compartments of the thigh, triggering muscular ischemia, acidosis, skeletal muscle death, and occasionally neurovascular compromise.

Of the three compartments of the thigh, the anterior compartment by far is the most commonly involved. There are some reports of compartment syndrome appearing as late as 8 days after injury, but usually symptom onset is within the first 24 h following injury [27]. One hallmark of compartment syndrome is pain that is out of proportion relative to the severity of the injury. Passive quadriceps extension will increase the pressures of the compartments and athletes will often present with the knee in nearly full extension, as this helps to mitigate pain. Paresthesia in the saphenous nerve distribution (anterior aspect of the knee and medial aspect of the leg and foot) can be a sign of more severe injury [28].

It is important to consider in compartment syndrome in the differential diagnosis and recognize early through compartment pressure testing and imaging to avoid poor outcomes. Whitesides et al. developed the classic method of compartment pressure testing in 1975 [29]. It is important to note that most of the work on compartment pressure measurement has been done on the leg, and not the thigh; therefore, all the available literature needs to be taken with that consideration. Measurement should be near the site of injury as differences as little at 5 cm can cause tissue pressure differences. It is imperative to determining pressure thresholds for treatment and diagnosis. Szabo et al. showed the relationship between pressure and physiologic nerve dysfunction [30]. In healthy muscle this is approximately 10 mmHg less than the diastolic blood pressure and is 20–30 mmHg less than DBP in damaged muscle. Others have suggested fasciotomy when pressure exceeds 30–35 mmHg. Robinson et al. treated six athletes with acute compartment syndrome of the anterior thigh following contusion and noted intraoperative pressures of 68–88 mmHg [31]. Rothwell managed nonoperatively 60 cases of quadriceps hematoma due to blunt trauma. Pressure readings were not done in this series; however, thigh circumference was increased up to 4 cm compared to contralateral side, suggestive of significantly increased pressure. All patients recovered without quadriceps weakness or decreased range of motion [32].

Fasciotomy and decompression should be done for acute-onset severe disease with associated neurovascular compromise and should be considered in the treatment of symptoms of ongoing pain despite conservative treatment. Anterior compartment fasciotomy should be performed through a mid-lateral longitudinal incision and wounds should be packed open. After 48 h there can be consideration for delayed primary wound closure versus skin grafting if required.

In the absence of progressively worsening symptoms or the development of neurovascular compromise, mild to moderate elevations of compartment pressures can be treated conservatively with observation, passive ROM, ice, heat, elevation, and analgesia [28]. Hyperbaric oxygen (HBO) increases tissue oxygenation and has been shown to have benefit in the treatment of injuries resulting in tissue ischemia, such as crush injuries or compartment syndrome [33]. The majority of the HBO treatment literature to date has been more in the treatment of trauma rather than athletic injuries. While HBO remains a promising treatment, further randomized, controlled trials are needed to extrapolate its use for the athletic population [34].

One final complication that can accompany thigh contusion or crush injury is a Morel-Lavallee lesion. This is triggered when the skin and subcutaneous fatty tissue abruptly separate from the underlying fascia. This is also referred to as a “closed degloving injury.” These effusions are most common in the trochanteric region and proximal thigh. Imaging with MR can present in a variety of ways. They can present as a hematoma with capillary ingrowth. More established lesions can appear like encapsulated cysts or seromas and have quite varied signal intensity. Based on the vascularity of these lesions, they can sometimes be difficult to distinguish from soft tissue neoplasm with increased vascularity. Treatments for Morel-Lavallee lesions have included compression, percutaneous aspiration with debridement, irrigation, and suction drainage. In recalcitrant cases either talc sclerosis or doxycycline sclerodesis has been successful [35].

Summary

Quadriceps contusions and their sequelae are common injuries in contact and collision sports. Prompt recognition and treatment are needed to prevent long-term disability. Initial management is recommended to prevent hematoma formation, including rest, ice, and compression, and many authors will argue that keeping the knee flexed at least 120° for the first 24–48 h will help to prevent hematoma onset and subsequent complication. Once the acute, inflammatory phase has resolved, the treatment mainstay is physical therapy. If pain increases or a palpable mass develops, one must be alert for the possibility of myositis ossificans, which can present in up to 20 % of cases. Rarely, acute compartment syndrome can complicate quadriceps contusion, necessitating operative intervention for fasciotomy.

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Quadriceps Tendon Ruptures

10

Ryan J. McNeilan and David C. Flanigan

Introduction

The lower extremity extensor mechanism, consisting of the osseous sesamoid patella, quadriceps tendon, and patellar ligament, is an upper-to-lower leg link crucial to coordinated upright ambulation and sport. While uncommon, compromise of the mechanism at any location is associated with debilitating consequences in athletes and nonathletes. The true incidence of quadriceps tendon ruptures is difficult to elucidate and has been sparsely reported in the literature. Quadriceps tendon ruptures accounted for 1.3 % of soft tissue injuries but less than 0.1 % of all trauma injuries in a 5-year trauma database [1]. Among a population of 93,224 soldiers followed for a period of 2 years, quadriceps tendon ruptures were reported in four soldiers, less than 0.01 % of the at-risk population [2].

The Greek physician Galen (131–201 AD) first reported a rupture of the knee extensor mechanism in a male wrestler [3]. Since Galen's initial report, numerous studies have detailed unilateral and bilateral quadriceps tendon ruptures. Ruptures of the quadriceps tendon appear to predominantly affect males with a male to female ratio of greater than 4:1 [1]. Additionally, African Americans appear to be at greater risk than Caucasians with an adjusted odds ratio of 2.89 [4]. Tears most commonly occur in those over 40 years of age and can be associated with medical comorbidities [1, 3].

Quadriceps tendon ruptures have been reported in a wide range of young athletes of both genders and races including wrestlers, weightlifters, triathletes, basketball, soccer, tennis, and football players [3, 5–11]. In an athlete, the quadriceps tendon is of paramount importance, and its function must be restored if continued participation in sport is desired.

Anatomy

The quadriceps musculature is the most massive portion of the knee extensor mechanism. Aptly named, the quadriceps is composed of the rectus femoris, vastus medialis, vastus lateralis, and vastus intermedius. These four muscles coalesce in a trilaminar fashion to form the quadriceps tendon approximately 3–5 cm proximal to the superior pole of the patella (Fig. 10.1). The superficial

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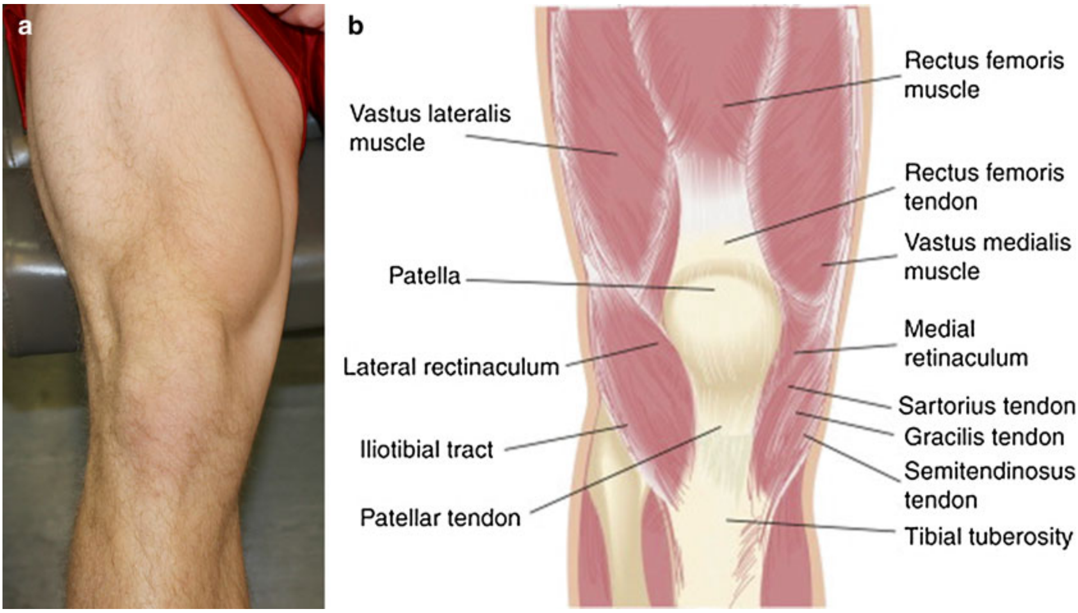

Fig. 10.1 (**a**) Surface anatomy of the knee in resisted extension. (**b**) Anatomical depiction of the underlying knee extensor mechanism. Part (**b**) was published in DeLee and Drez's Orthopaedic Sports Medicine, 3rd Edition, DeLee JC, Drez D, Miller MD, editors. Chapter 22: Patella, p. 1533–77, Copyright Saunders, an imprint of Elsevier (2010)

plane contains the rectus femoris; the middle plane contains the vastus lateralis and medialis; the deep plane contains the vastus intermedius [3, 12–14]. The tendon created as a result of the aforementioned coalescence averages 8 mm in thickness and 35 mm in width [15]. The clinically relevant medial and lateral retinaculum are aponeurotic extensions of the medial and lateral vastus musculature. Microscopically at its patellar insertion site, the quadriceps tendon collagen fibers are continuous and interdigitate between individual bony lamellar systems but are not integrated into the lamellar structure of the bone [16].

The vascular supply of the quadriceps tendon is of particular importance and has been described in detail [17]. The blood supply of the tendon consists of medial, lateral, and peripatellar arcades branching from muscular perforators of the deep and superficial femoral arteries, the descending genicular artery branch of the superficial femoral artery, and the superior medial and superior lateral genicular arteries from the popliteal artery. The tendon possesses an oval-shaped area of relative hypovascularity in its central, deep portion between 1 and 2 cm proximal to the superior pole of the patella [17]. This vascular watershed region is clinically important as is plays a role in rupture risk and tendon healing potential.

Biomechanics

Within the extensor mechanism, the osseous patella acts as a fulcrum, increasing the extensor moment arm and thereby transmitting the longitudinal contractile force at a greater distance from the knee axis of rotation [13]. Force transmission through the knee extensor mechanism occurs in a complex but coordinated fashion. Huberti and colleagues demonstrated variability in the force ratio between the quadriceps tendon and patellar ligament with varying degrees of knee flexion, a concept they coined "the extensor mechanism force ratio" [18]. According to their biomechanical study, the predominant force lies within the patellar ligament at a knee flexion angle of 30°, whereas the forces are equal at 50° of flexion. The quadriceps tendon has a mechanical advantage at these smaller flexion angles, and the patellofemoral contact area is located at the distal end of the patella. With knee flexion beyond 90°, the force in the quadriceps tendon is greater than the force in the patellar ligament. The contact area on the patella shifts proximally with increasing knee flexion, giving the patellar tendon a mechanical advantage [18]. This, in turn, relates the position of knee flexion to the likelihood of tendon failure. At a position of knee flexion less than 45°, the patellar ligament is more likely to be injured. In positions greater than 45°, the quadriceps tendon is at higher risk for tensile failure.

There is a paucity of data concerning the absolute in vivo strength of the human quadriceps tendon and tensile loads within the tendon during common activities of walking, running, or jumping. In a cadaveric study of young males, the quadriceps tendon was capable of withstanding average loads of greater than 2,000 N prior to failure [19].

Etiology and Mechanism of Injury

The quadriceps tendon is infrequently the site of knee extensor mechanism disruption, as the mechanism most commonly fails through fracture of the patella [3]. The quadriceps tendon is remarkably resistant to rupture. In an early study by McMaster, the tensile strength and points of rupture of adult rabbit quadriceps tendons were evaluated [20]. In his study, approximately 50 % of a tendon's fibers had to be severed for rupture to occur, even when subjected to extremely high forces. Rupture at the osteotendinous and musculotendinous junctions or through muscle substance occurred at lesser loads [3, 20]. These data suggest that healthy quadriceps tendons do not rupture and some preexisting degeneration must be present for the mechanism to fail within in the tendon, an idea that has been widely accepted [3, 12, 17, 20–23].

Tendon degeneration may be secondary to overuse (particularly in the athletic population), anticipated changes with aging, tendon vascular disruption or compromise, or any of a multitude of systemic medical conditions. Kannus and Jozsa reported on the histological characteristics of biopsies of spontaneously ruptured tendon obtained during reparative procedures in 891 patients [23]. Characteristic histopathologic patterns in the ruptured tendons included hypoxic degenerative tendinopathy, mucoid degeneration, tendolipomatosis, and calcifying tendinopathy, either alone or in combination. In their study, no ruptured tendon was histologically normal. Comparatively, age-matched cadaveric controls were histologically normal in greater than 2/3 of specimens.

The hypovascular region of the quadriceps tendon may play a role in quadriceps tendon rupture etiology. Most tendon ruptures/strains occur at the musculotendinous or osteotendinous junction. The quadriceps tendon will most commonly rupture near its osteotendinous insertion and hypovascular region [17, 21, 24]. In a systematic review of quadriceps tendon ruptures, greater than 75 % of ruptures were identified within 2 cm of the superior pole of the patella [25]. Delayed healing in this location secondary to hypovascularity compromises the tendon's ability to withstand repetitive microtrauma.

Systemic conditions altering the vascular supply and overall tendon integrity have been associated with tendon ruptures. Many of these conditions negatively affect the tendon microvasculature. This creates an additional insult to the already hypovascular region of quadriceps tendon and increases the tendon's susceptibility to rupture. The quadriceps tendon is not exempt from the systemic microvascular compromise induced by diabetes. Additionally, hyperparathyroidism, systemic lupus erythematosus, osteomalacia, and the use of steroids can also cause microscopic damage to the vascular supply [26, 27]. Renal disease and uremia can weaken the quadriceps mechanism by causing muscle fiber atrophy and changes within the collagen structure [28]. Synovitis and fibrosis may result from chronic inflammatory changes associated with rheumatoid and gouty arthritis [29, 30].

Systemic conditions/medications associated with quadriceps tendon rupture include the following:

- Diabetes
- Hyperparathyroidism
- Systemic lupus erythematosus
- Gout

- Pseudogout
- Uremia
- Rheumatoid arthritis
- Steroids
- Fluoroquinolones

Of particular importance in evaluation of the athletic population, anabolic steroid use has been shown to alter the structural and mechanical properties of tendon in animal studies [31, 32]. Several case reports have linked anabolic steroid usage to tendon rupture, including a case of bilateral quadriceps tendon ruptures [33, 34]. While a definitive cause–effect relationship has not been established, animal studies suggest the deleterious effects of their usage on tendon health.

When quadriceps tendon ruptures do occur, it is almost uniformly indirect in nature. While exceedingly rare, reports of rupture resulting from direct trauma and laceration are also present in the literature [3, 24]. The rupture most commonly occurs as the result of an eccentric contraction of the extensor mechanism against a sudden load of body weight with the foot planted and knee flexed [3, 8, 12, 21, 35]. This eccentric contraction is commonplace in many sporting activities and occurs any time an athlete lands from a position of elevation or performs the lowering phase of a squatting maneuver (Fig. 10.2a–h).

Clinical Presentation

A rupture of the quadriceps tendon is often a clinical diagnosis based on history and physical examination. Patients will commonly present with the triad of acute onset knee pain, inability to actively extend the knee, and a suprapatellar gap (Fig. 10.3) [3, 24, 27, 36]. This triad is commonly accompanied by a report of a fall or sense of knee instability following the acute onset of knee pain. The pain is often intense and tearing in nature. On physical examination, anterior knee edema is often present, and a gap in the tendon may be appreciated with palpation. The patient is unable to actively extend the involved knee and experiences difficulty maintaining a straight leg raise against gravity.

With a partial tear or a complete tear with an intact patellar retinaculum, the patient may retain the ability to hold straight leg raise against gravity and extend the knee, albeit with much less force than the non-involved limb. Active knee flexion is retained. If initial presentation is not obvious or severe pain precludes adequate examination, knee aspiration and intra-articular anesthetic injection can help relieve the pain and allow the physician to more accurately assess the extensor mechanism. Despite the apparent simplicity in presentation and clinic diagnosis, the aforementioned confounders may mask or delay the diagnosis of a quadriceps tendon rupture. Delays of days to months and overall misdiagnosis rates ranging from 10 to 50 % have been reported in the literature [12, 37, 38].

Imaging

Although the diagnosis of quadriceps tendon rupture is usually evident following physical examination, further workup with diagnostic imaging is recommended for confirmation and identification of concomitant knee pathology. At a minimum, biplanar radiographs of the knee should be obtained for evaluation of the osseous knee structures and relative location of the patella. The lateral knee radiograph is particularly useful in the characterization of extensor mechanism disruptions. Quadriceps tendon ruptures may be identified by disruption of the tendon's shadow [38]. The relative position of the patella can be evaluated by the previously detailed Insall-Salvati [39] or Blackburne-Peel [40] ratios. Of the two, the Blackburne-Peel ratio has been shown to be the most reproducible and consistent measure of patellar height [41]. The lateral radiograph and these defined ratios will commonly demonstrate a low-lying patella (patella baja). It should be noted, however, that a low-lying patella and ratio measures outside the normal reported range are not mandatory diagnostic prerequisites for quadriceps tendon ruptures.

Ultrasonography and magnetic resonance imaging (MRI) are two additional useful imaging

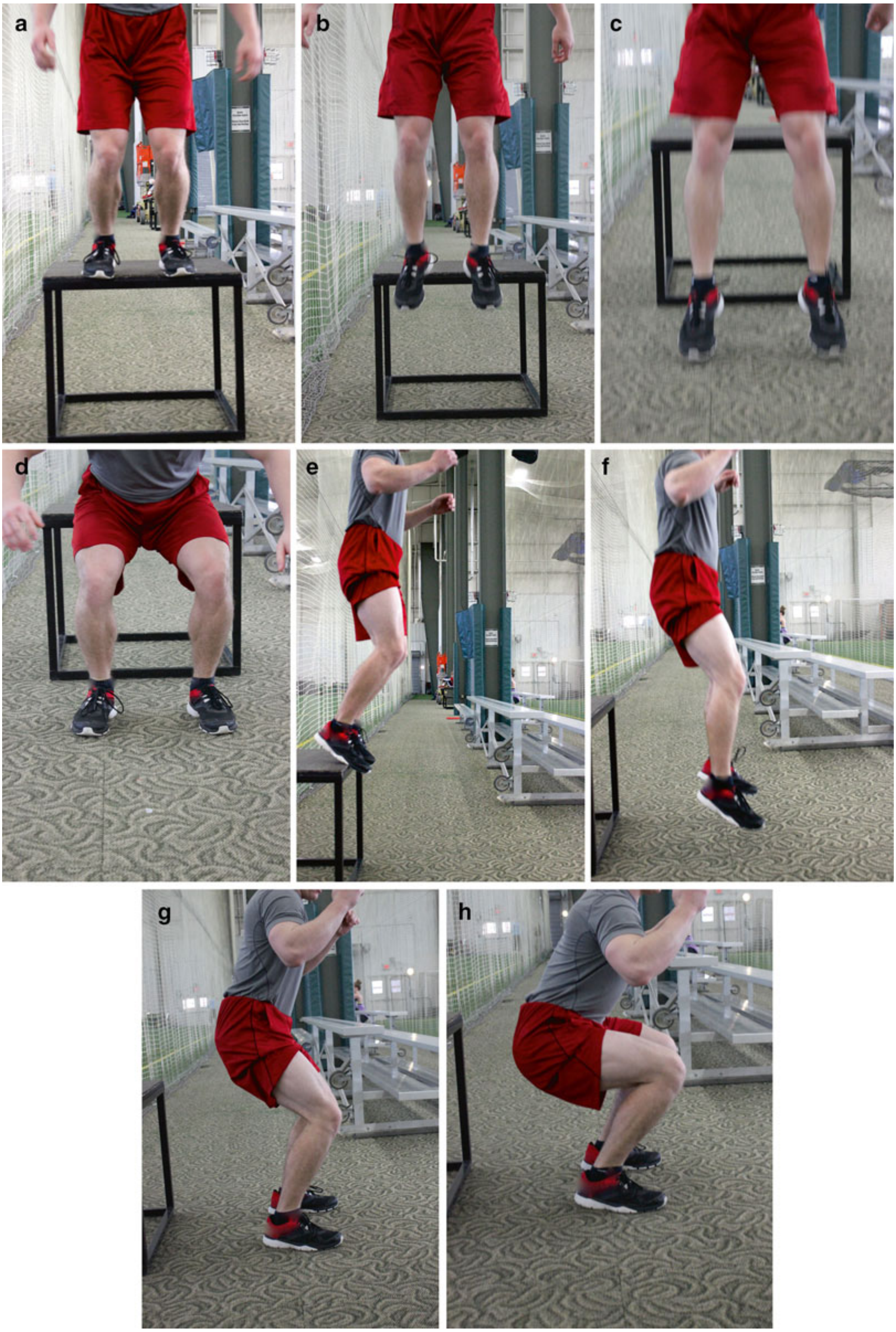

Fig. 10.2 (**a**–**h**) Sequence of landing from position of height. Note the eccentric body weight load on the quadriceps with the foot planted and knee flexed

Fig. 10.3 Palpation of the ruptured quadriceps tendon demonstrates a palpable suprapatellar gap

modalities in the diagnosis of quadriceps tendon ruptures. In combination with physical examination, ultrasound has been shown to be a highly sensitive and specific means of quadriceps tendon rupture assessment [42–44]. Complete tears will demonstrate free end tendon fibers with intervening hypoechoic to anechoic area. The reliability of ultrasound remains operator dependent. While ultrasound results may be obscured by hematoma or edema associated with the rupture, MRI consistently and accurately depicts the injury and its location (Fig. 10.4) [43, 45, 46]. Perhaps the greatest benefit of MRI is its ability to identify concomitant knee pathology, although this occurs infrequently in disruptions of the knee extensor mechanism [47].

Treatment

The treatment strategy varies based on the presence or absence of a complete rupture and the chronicity of the rupture.

Partial

A conservative, nonoperative approach is the initial management of choice when a diagnosis of partial rupture is made. Traumatic hemarthrosis and effusion have been shown to decrease quadriceps strength [48]. Early treatment should thus consist of aggressive treatment of knee effusion with ice, compression, anti-inflammatory medication, and possibly knee aspiration to evacuate the hemarthrosis and promote rehabilitation. Operative treatment may be indicated if nonoperative management fails to provide resolution of symptoms. If one or more of the tendon layers are intact, partial ruptures can be treated with excision of the scar tissue and side-to-side closure of the tendon [49].

Complete

Weakness and long-term disability associated with nonoperative management of complete quadriceps tendon ruptures have made operative repair of the ruptured tendon the treatment strategy of choice. When the diagnosis of a complete quadriceps tendon is made, prompt referral to an operative orthopedic surgeon is recommended as delay in operative repair may result in poorer outcomes secondary to retraction of the proximal tendon and atrophy of the quadriceps musculature [6, 50, 51].

The basic tenets of operative repair of quadriceps tendon ruptures including the use of suture to approximate the tendon to and through its patellar remnant have remained unchanged since the procedure was first reported in the 1880s [3]. Based on these tenets, numerous effective surgical strategies have been derived for the management of this injury; no technique has been proven to produce superior results [3, 7, 49–51]. A randomized, controlled trial comparing outcomes of quadriceps tendon ruptures repaired by the various techniques has not been completed. The type of surgical treatment is largely dependent on the location of the rupture within the tendon and surgeon preference.

For surgical intervention, the patient is placed supine on an operating room table, frequently with a bump under the involved hip to prevent external rotation of the extremity. The anatomic surgical approach shows little variability across treatment types and consists of an approximately 10 cm midline longitudinal incision over the anterior knee to expose the extensor mechanism. If hematoma is present, this is evacuated to allow

Fig. 10.4 (**a**) Sagittal proton-density turbo spin-echo MRI of right quadriceps tendon rupture. (**b**) Sagittal proton-density turbo spin-echo fat-saturated MRI of right quadriceps tendon rupture. Note the anterior effusion, complete discontinuity of the quadriceps tendon, and wavy appearance of the continuous patellar tendon

visualization of the ruptured tendon ends. The tendon ends are debrided of grossly degenerative tissue to prepare them for repair.

For mid-substance tears, an end-to-end primary repair with heavy nonabsorbable suture is an effective treatment strategy. Using a No. 2 or No. 5 nonabsorbable suture, continuous running stitches are sewn up and down the lateral borders of the free proximal and distal tendon ends in a locking fashion. This is repeated along the medial borders of the free ends of the ruptured tendon, leaving four free suture ends from the proximal and distal tendon remnants. The corresponding sutures are then tied with the knee in full extension, resulting in four knots at the site of tendon rupture. The repair may be augmented with additional simple interrupted sutures at the rupture site. The medial and lateral patellar retinaculum are then reapproximated with another heavy nonabsorbable suture to complete the repair. The stability of repair and patellar tracking are then tested by taking the repaired knee through gentle range of motion.

Ruptures at or near the osteotendinous junction typically require a slightly more advanced repair strategy. Suture anchors at the superior pole of the patella or a series of three drill holes longitudinally through the patella may provide appropriate recreation of the quadriceps tendon portion of the extensor mechanism (Fig. 10.5). The transosseous technique is most commonly utilized. Two separate heavy nonabsorbable sutures are passed through the medial and lateral portions of the tendon in a locking fashion as described above, resulting in four equal-length tendon strands at the free tendon edge. A trough is made in the superior margin of the patella with a high-speed burr, thereby creating a bleeding bone bed to achieve tendon to bone healing. The trough must be created horizontally in the midpoint of the superior pole of the patella to prevent abnormal tilt when the tendon is reapproximated. A 2.0 mm drill is then used to create three parallel transosseous patella drill holes with starting points in the trough 1 cm apart. It is important that the drill holes are parallel to the patellar

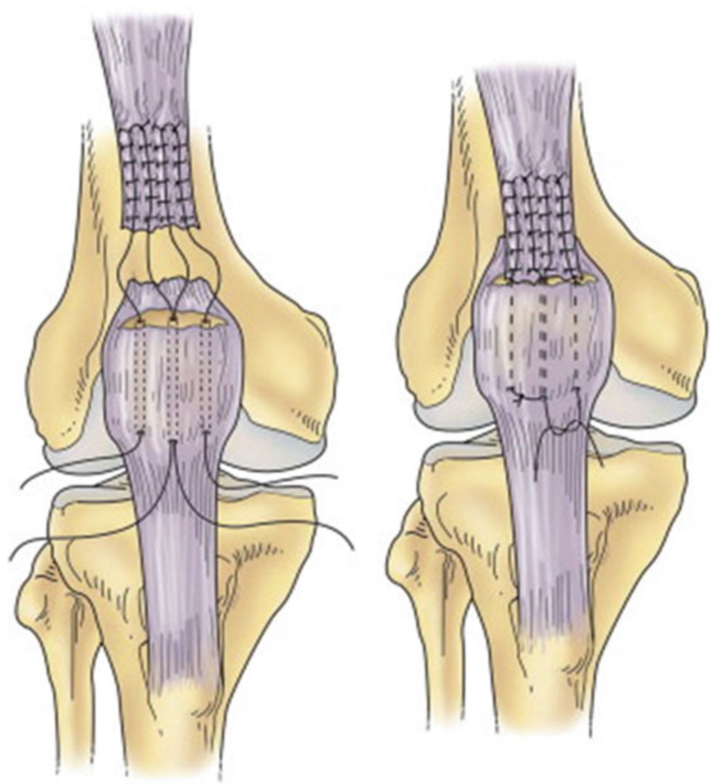

Fig. 10.5 Depiction of surgical repair with suture through transosseous tunnels. This figure was published in Insall and Scott Surgery of the Knee, 5th Edition, Seidenstein AD, Farrell CM, Scuderi GR, Easley ME, Chapter 66: Quadriceps and patellar tendon disruption, p. 696–710, Copyright Churchill Livingstone (2012)

articular surface and each other. Convergence should be prevented as this may cause failure of the repair by suture pullout through the bone bridge. The sutures are shuttled through the patellar holes with the use of a Hewson suture passer so that one suture end passes through each of the lateral and medial holes and two pass through the medial hole. Alternatively, Beath pins can be used to create holes and shuttle the sutures. The sutures are tied distally with the knee in full extension, resulting in two knots at the inferior pole of the patella (Fig. 10.6). The medial and

Fig. 10.6 (**a**) Planned operative incision with outline of patella and tibial tubercle. (**b**) Debrided edges of the ruptured quadriceps tendon reflected. (**c**) Debrided edges of the ruptured quadriceps tendon opposed. (**d**) Creation of the trough in the superior pole of patella with burr. (**e**) Tendon is sutured with heavy nonabsorbable suture in locking fashion along its medial and lateral borders. (**f**) Beath needle is drilled through the patella parallel to its articular surface. (**g**) Beath needles in parallel configuration with 1 cm spread (lateral suture has been threaded through drilled hole). (**h**) Remaining sutures shuttled through the drilled holes. Note the reapproximation of tendon to the superior pole of patella. (**i**) Cerclage "relaxing suture" sewn through medial retinaculum. (**j**) Cerclage "relaxing suture" tied with knee in flexion. (**k**) Sutures shuttled through the patella drill holes are tied at inferior pole of patella with knee in extension. (**l**) Reapproximation of the quadriceps tendon

Fig. 10.6 (continued)

lateral patellar retinaculum are then reapproximated with a heavy nonabsorbable suture. Following recreation of the extensor mechanism, the knee is gently ranged from 0 to 90° to ensure absence of gapping, appropriate tension, and appropriate patellar tracking. The repair may be augmented with a cerclage suture [52]. In this technique, a heavy nonabsorbable "relaxing suture" is passed through the quadriceps tendon proximal to the locking stitches, woven down through the medial and lateral retinaculum, passed below the distal pole of the patella, and tied with the knee in 30° of flexion to reinforce the repair. Alternative approaches to repair including the use of a Leeds-Keio ligament [53], Dacron vascular graft [54], or Mersilene tape [55] have been described but are used infrequently.

Chronic

Unfortunately, a delayed or missed diagnosis of a quadriceps tendon is not a rare occurrence [12, 37, 38]. Management of this subset of tears requires a different treatment approach as scarring and tendon retraction may prohibit a direct

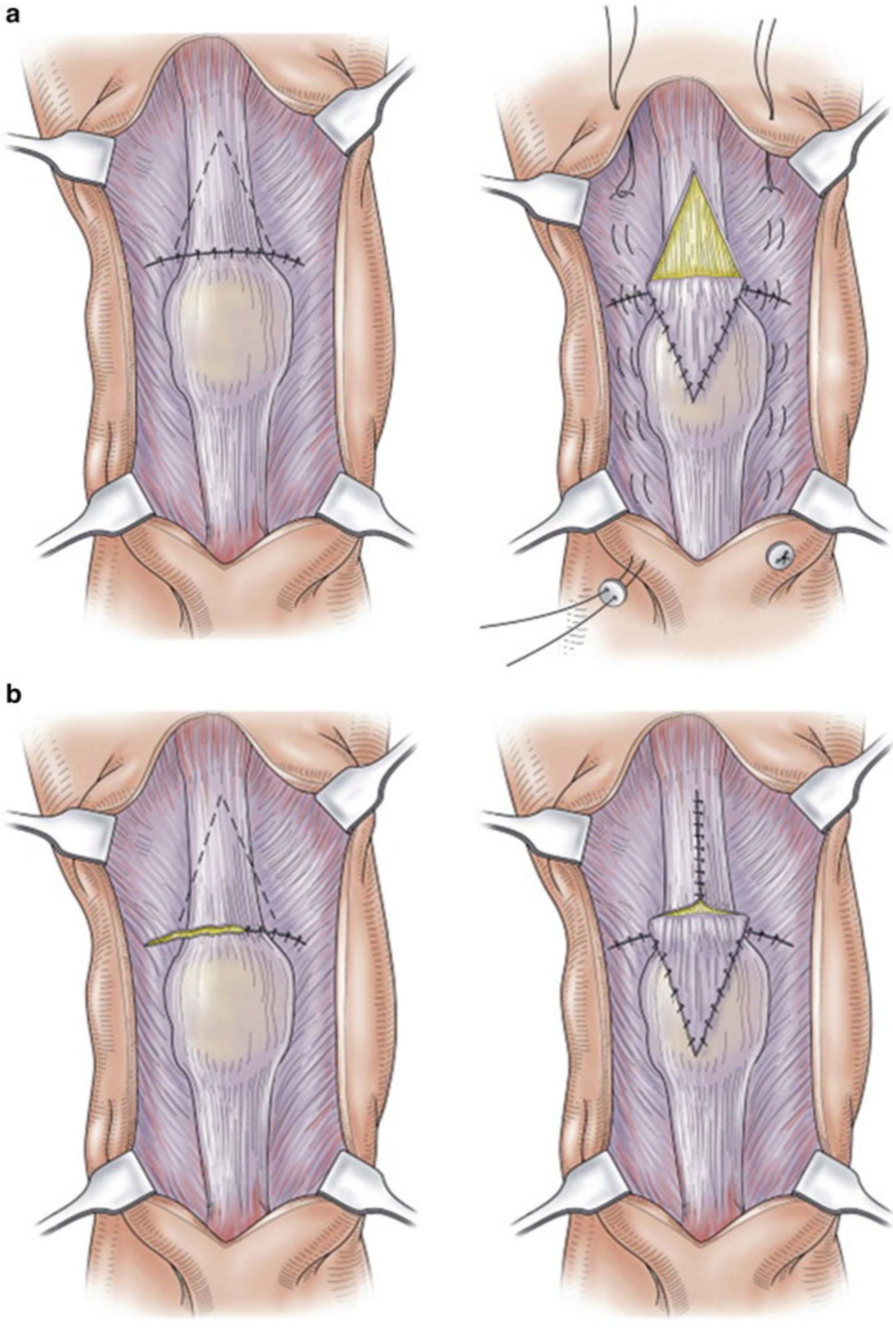

Fig. 10.7 (**a**) Scuderi technique. (**b**) Codivilla technique. These figures were published in Insall and Scott Surgery of the Knee, 5th Edition, Seidenstein AD, Farrell CM, Scuderi GR, Easley ME, Chapter 66: Quadriceps and patellar tendon disruption, p. 696–710, Copyright Churchill Livingstone (2012)

end-to-end or tendon-bone repair of the tendon. Elevation of the quadriceps from the femoral shaft provides additional length to bridge small retraction gaps, but scarring and large gaps often limits its utility. The inverted V turndown flap techniques popularized by Scuderi and Codivilla can provide reinforcement and additional length to the chronic quadriceps tendon repair (Fig. 10.7)

[24]. In this technique, the ends of the quadriceps tendon are first approximated with a heavy non-absorbable suture. This is followed by the creation of an inverted V-shaped flap (partial thickness in Scuderi technique and full thickness in Codivilla technique) of the proximal quadriceps tendon with its base 1 cm proximal to the tendon tear. The flap is then folded distally so that the body of the V overlies the rupture site and the apex of the V is distal. In the full-thickness Codivilla technique, the proximal portion of the tendon is then repaired side to side to minimize compromise of the tendon.

Rehabilitation

Exact rehabilitation protocols are variable from surgeon to surgeon and are determined by type of tear, surgeon experience, and intraoperative assessment of the repaired tendon. The first 3–6 weeks of rehabilitation for a partial quadriceps tendon injury consisted of immobilization with a hinged knee brace locked in extension and weight bearing as tolerated on the involved extremity. The second phase of management focuses on unlocking the knee brace, regaining knee flexion, and progression to full weight bearing. The final phase consists of continued focus on knee range of motion and strengthening with return to sport when both return to pre-injury levels, usually around 4–6 months.

Conventional rehabilitation following surgical repair of complete ruptures consisted of weight bearing as tolerated on the involved extremity with a hinged knee brace locked at 0° for 4–6 weeks [36, 50, 56, 57]. Recently, early motion has been advocated following operative repair of the extensor mechanism with authors championing motion as a method to limit muscular atrophy and stiffness while accelerating tendon healing [52, 58, 59]. Based on this data, range of motion restrictions during the first 6 weeks should be based on stability of repair as tested in the operating room, but are usually limited to 0° to 60–90° of knee flexion. At 6 weeks postoperatively, the patient may progress to full range of motion, though terminal-/end-range quadriceps stretching should be avoided until 8 weeks. No isolated, open-chain isotonic quadriceps strengthening should be performed for 8 weeks. The hinged knee brace is to be retained until the patient obtains full knee flexion and can perform a straight leg raise without extensor lag. Strengthening, proprioception, and range of motion exercises continue throughout ensuing weeks with return to sport-specific rehabilitation activities at 4–6 months and return to sport when the patient has regained full knee range of motion, 5/5 lower extremity strength, and greater than 85–90 % performance of involved side versus uninvolved side in functional and isokinetic strength testing. Our preferred rehabilitation protocol is depicted in Table 10.1.

Outcomes

While distinctive data regarding the outcome of partial tears of the quadriceps tendon are lacking in the literature, nonoperative treatment resulted in successful outcome and return to full participation in a triathlete [10]. If nonoperative management fails, surgical treatment can often return athletes to sports [11, 60].

Outcome data regarding the operative repair of complete quadriceps tendon ruptures are more prevalent in the literature. Outcomes are generally favorable following operative repair regardless of fixation method or postoperative rehabilitation protocols, but retaining elite level athletic functionality has proven difficult (Table 10.2).

As early as 1958, Scuderi reported excellent outcomes in 11/13 patients treated with operative repair [24]. In their review of 36 ruptures, Siwek and Rao found that all patients undergoing early operative repair had good or excellent results based on final strength and range of motion. The results were less favorable in those with delays to operative intervention [61]. Several small retrospective reviews in the late 1990s and early 2000s reported a majority of good to excellent results with a common complication of decreased muscle strength, irrespective of repair technique [52, 59, 62, 63]. Ramseier et al. reported all good to

Table 10.1 Quadriceps tendon repair postoperative rehabilitation protocol

Phase	WB	ROM	Rehab	Goals
Week 0–2	WBAT	0 to 60–90°[a]	• Gentle medial and lateral patellar mobilizations • Ankle pumps, gluteal sets, hamstring sets • Modalities to control pain and edema	• Protect repair • Control pain and edema • Fair to good volitional quad activation
Week 2–4	WBAT	0 to 60–90°[a]	• 4-way patellar mobilizations • Heel slides • Calf, hamstring, hip stretching • Quad sets, submaximal • 4-way SLR with brace locked in extension • Seated hamstring curl, no resistance	• Protect repair • PROM 0–60° • Normal gait • SLR without extensor lag
Week 4–6	WBAT	0 to 60–90°[a]	• Progress 4-way patellar mobilizations • Heel slides, quad sets, submaximal • 4-way SLR with brace locked in extension • Seated hamstring curl with light T-band resistance	• Gait with normal mechanics and no reactive effusion • Knee ROM to surgeon limit • Good scar quality and mobility
Week 6–8	WBAT	Full	• Wean from brace when full flexion and SLR without extensor lag • AROM knee extension and flexion • Stationary bike • Closed chain quad strengthening • Weight shifts, progress to single leg stance/proprioception • Core/hip stabilization	• Restore full AROM and patellar mobility • Normal gait without brace • Resistive exercise without reactive effusion/pain
Week 8–12	WBAT	Full	• End-range quad stretching • Stationary bike • Elliptical/StairMaster at 10 weeks • Progress closed chain strengthening • Isotonic quadriceps strengthening • Single leg proprioception on various surfaces	• Full ROM • Single leg stance for 30 s • 5/5 strength of all other lower extremity muscles
Week 12–16	WBAT	Full	• Partial WB shuttle plyometrics, bilateral to unilateral • Progress to full WB step downs • Slideboard	• Appropriate mechanics with rehab activities • No pain, effusion
Week 16–24	WBAT	Full	• Recreational swimming • Initiate sports-specific exercise • Increase height of step downs • Initiate jogging • Progress dynamic functional activity—figure of 8, zigzag, side shuffle	• Appropriate mechanics with rehab activities • No pain, effusion
Return to Sport				• Full ROM • 5/5 lower extremity strength • >85–90 % performance compare to uninvolved in functional hop testing and isokinetic strength testing

WB weight bearing, *WBAT* weight bearing as tolerated, *ROM* range of motion, *PROM* passive range of motion, *AROM* active range of motion, *SLR* straight leg raise

[a]Based on stability of repair during intraoperative testing

Table 10.2 Outcome of quadriceps tendon repair—general population

Author/date	No. patients	Mean age of patient (years)	Surgical technique	Post-op protocol	Follow-up, number of patients/ mean time	Outcome
Scuderi [24]/1958	18	48.2	Running absorbable catgut with partial thickness quad flap + wire augment	Cast immobilization ×6 weeks	13/8–24 months	11/13 excellent—complete return of extension and <15° flexion loss
Siwek and Rao [61]/1981	34	NR	Simple suture ± wire augment	NR	NR	Early: all excellent or good, ROM 0–120° Delayed: 50 % good, 50 % unsatisfactory, ROM <90° flexion in 5/6
Rasul and Fischer [50]/1993	19	47.4	Simple suture, patella drill holes	6 weeks immobilization, full weight bearing	19/4.5 years	Average ROM 0–116°, muscle strength deficit/ atrophy noted in only 2 patients
Konrath et al. [59]/1998	40	56	Simple suture, patella drill holes, simple suture + wire augment	6 weeks careful mobilization, partial weight bearing	37/48 months	Average Lysholm score 87/100, average ROM 2–125°, 53 % of patients had >20 % of strength deficit at low speed and 32 % of patients had >20 % of strength deficit at high speed
O'Shea et al. [62]/2002	27	69.4	Simple suture, patella drill holes, wire augment	6 weeks immobilization, partial weight bearing	19/22.7 months	Average "excellent," average ROM 116.25°, no significant strength deficits, no re-ruptures
Wenzl et al. [63]/2004	35	53.3	Simple suture, patella drill holes, patella drill holes + wire augment	6 weeks immobilization ROM to 60°; partial weight bearing	29/55.4 months	Average Lysholm score 92.5/100, average ROM 131.7°, 38 % of patients with >20 % quad strength deficit at low speed and 27.6 % had >20 % strength deficit at high speed
Ramseier et al. [64]/2005	21	47.3	Simple suture, patella drill holes	6 weeks immobilization	17/57 months	No significant strength, ROM, or clinical score deficits
West et al. [52]/2008	20	55	Patella drill holes + cerclage suture augment	6 weeks 55° flexion; full weight bearing	20/4 years	All returned to pre-injury activity levels, quad strength deficit 35 % at low speed, 38.8 % at high speed, no re-ruptures

excellent results with no significant range of motion or strength deficits compared to the non-involved leg [64].

In the largest single review of quadriceps tendon repairs, Konrath et al. studied 51 quadriceps tendon ruptures in 39 patients. In their study, 92 % of patients were satisfied and 84 % returned to their previous occupations. In contrast, the majority (51 %) were unable to return to the same level of recreational activity. They reported average strength losses of 12 % in the quadriceps tendon and 14 % in the hamstrings following injury and operative repair [59]. The work of Kelly et al. corroborates the potentially serious implications of quadriceps tendon ruptures in athletes as no athlete in their small series achieved excellent functional outcome, defined by no pain and full return to pre-injury activity [6]. West et al. reported return to sport following operative repair in 58 % (7/12) of patients sustaining a quadriceps rupture

Table 10.3 Outcome of quadriceps tendon repair—athletes

Author/date	Patients	Sport	Surgical technique	Outcome
Kelly et al. [6]/1984	3	Basketball	Patella drills holes ± wire augment	No excellent clinical (atrophy <0.5 cm, no patellar compressive tenderness, <5° loss of flexion) or functional (no pain with full return to pre-injury level of activity) result, retirement of 1 professional basketball player
West et al. [52]/2008	12	Basketball, softball, volleyball, weight lifting	Patella drill holes + cerclage suture augment	58 % (7/12) returned to sport within 6 months, 2 patients chose not to return to sport, 3 others did not routinely participate in sport
Boublik et al. [8]/2013	14	Professional American Football	Patella drill holes, suture anchor	78.6 % (11/14) "completely recovered" (full strength and no pain), only 50 % (7/14) returned to play in NFL, no returning player received accolades (2 patients participated in Pro Bowls before injury)

NFL National Football League

during sporting activity [52]. Boublik et al. examined quadriceps tendon injuries in National Football League (NFL) players. In their study, 14 quadriceps tendon injuries (11 complete, 3 partial) were identified; all underwent primary operative repair. Postoperatively, 50 % (7/14) returned to play a game in the NFL [8]. These data suggest that, while not impossible, return to pre-injury athletic function is not guaranteed following a quadriceps tendon rupture (Table 10.3).

Complications

While outcomes are generally satisfactory, especially in those not desiring full return to elite athletic activity, the management of quadriceps tendon ruptures is not without potential complications. As noted above, loss of absolute quadriceps strength and resultant extensor lag is a common complication secondary to disruption of the anatomic tendon and muscular atrophy [57–59, 62, 63]. Loss of motion, particularly knee flexion, is also a common complication following repair of quadriceps tendon rupture. Rehabilitation goals are therefore focused on regaining strength and range of motion with early mobilization. As with any tendon repair, re-rupture is a potential complication, and although exceedingly rare, instances of re-rupture have been reported in the literature [51, 59, 64]. There is no apparent correlation of re-rupture rates to surgical repair technique or time to postoperative mobilization. Deep vein thrombus (DVT) and pulmonary embolism have also been reported following surgical intervention for quadriceps tendon ruptures. O'Shea et al. reported one pulmonary embolism in their review of 27 patients. Their postoperative protocol included immobilization and partial weight bearing for 6 weeks [62]. Wenzl et al. reported two DVTs and one pulmonary embolism leading to death in their review of 35 patients. In their study, patients were immobilized or allowed up to 60° of knee flexion and partial weight bearing for 6 weeks [63]. There is a single report of the development of acute compartment syndrome of the thigh following quadriceps tendon rupture [65].

Summary

While a rare occurrence, a quadriceps tendon rupture can have devastating consequences in athletes and nonathletes alike. A healthy quadriceps tendon is highly resistant to rupture. Repetitive trauma from overuse and compromise of an already tenuous area of tendon hypovascularity secondary to systemic conditions or steroid use can predispose the tendon to rupture. When rupture does occur, it is almost uniformly indirect in nature and is the result of an eccentric contraction of the extensor mechanism against a sudden load of body weight with the foot planted and knee flexed. Patients will commonly present with the triad of acute onset of knee pain, inability to actively extend the knee, and a suprapatellar gap. Imaging studies including knee X-rays, ultrasound, and MRI can assist diagnosis and will demonstrate a low patellar position and compromise of the quadriceps tendon continuity. Partial tears may be managed with a trial of nonoperative management. Operative repair is recommended for optimal outcome in complete ruptures. Surgical intervention consists of the use of a heavy nonabsorbable locking suture construct to repair the tendon end-to-end or through drilled patellar tunnels depending on the location of the tear. Outcomes are generally favorable, but complications including stiffness and persistent quadriceps weakness may preclude return to prior recreational activity levels, especially in elite athletes.

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Rehabilitation of Quadriceps Injuries

11

Jake Bleacher

Rehabilitation of Muscle Injuries

There are no standard protocols in the literature for the treatment of muscle injuries in sports, and many treatments lack the scientific evidence to support their use [1–8].

However, in the majority of cases, muscles respond to conservative care with rest, modalities, and a progressive rehabilitation program aimed to restore the strength and mobility of the muscle to preinjury levels. This is coupled with the fact that the muscle has an innate ability to repair itself allowing for adequate healing and the application of controlled stresses at appropriate intervals [1]. In general, the rehabilitation consists of three stages culminating in return to sport when the involved leg has symmetrical strength, ROM, endurance, and power as the uninvolved leg. The successful completion of each phase is dependent on the criteria that the activity be performed in a relatively pain-free manner (Table 11.1).

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Acute Stages: 0–5 Days

In the first 24–72 h, follow the RICE (rest, ice, compression, elevation) principles to prevent worsening of the initial injury. They consist of the application of ice at 15–20 min intervals with 60 min between applications to lower intramuscular temperature and decrease blood flow (shown to be 50 %) along with compression and elevation, which also serve to minimize interstitial fluid accumulation [1, 6]. In the case of contusions, it has been recommended that, in addition to the application of ice and elevation, the knee be splinted in a brace or elastic compression wrap with the knee in a flexed position for the first 24 h to limit hematoma formation. The use of crutches is recommended in the acute stages for those athletes who have sustained a grade II or grade III tear or contusion to minimize additional stress to the injured muscle and where there is evidence of an antalgic gait pattern [1, 9, 10].

Repair Phase: 5–7 Days to 6 Weeks

The repair phase of muscle begins approximately 5–7 days after injury and can last up to 6 weeks [1, 8, 9]. It is during this phase when more active therapies may begin to facilitate healing without risking the deleterious effects of immobility, including muscle atrophy, and excessive scar tissue formation [11]. It has been shown that early mobilization facilitates the healing process with improved

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Table 11.1 Rehabilitation guidelines following quadriceps injury

	Modalities	Therex	Ambulation	Manual therapy	Functional exercise
Acute (0–5 days)	RICE: rest, ice, compression, elevation (0–72 h)	None	Crutch ambulation for grade II/III strains	None	None
Repair (5 days–6 weeks)	NMES: neuromuscular electric stimulation to improve quadriceps activation	Early: (1–3) AROM, AAROM heel slides, quad sets, 4-way SLR, bike, core exercises	Normalize gait pattern	AAROM/PROM *pain-free range	Closed chain exercises with good volitional quad: step-ups, leg press, lunges
Remodel (7–12 weeks)		PREs: isotonic, isokinetic	Conditioning: jogging, bike, elliptical	Cross-friction; Graston; contraction/relaxation	Quad eccentrics, plyometrics
Return sport		WNL strength: isokinetic functional exercises	Interval running, sprinting	WNLs PROM quadriceps	Sport-specific exercises without pain

*Emphasizing importance of pain free Rom

alignment and regeneration of myofibers [1]. Some early active therapies include (active range of motion [AROM], active assistive range of motion [AAROM]) heel slides, stationary bike, and walking on a treadmill to normalize gait pattern. Care should be taken to avoid overly aggressive ROM or exercises in the early phases, especially with larger injuries, as they can result in delayed healing and complications such as myositis ossificans [9, 12, 13]. The use of modalities such as therapeutic ultrasound and neuromuscular electrical stimulation (NMES) is warranted to decrease pain and to improve quadriceps muscle activation, as experimental studies have concluded that pain and effusion can lead to quadriceps inhibition [14]. Maintaining a level of aerobic fitness during the convalescent period should be considered with low-impact activities such as swimming and the use of upper body ergometer (UBE) to minimize effects of deconditioning [9].

The progression to strengthening exercises during the repair phase is based on biologic healing principles of the muscle and guided by symptoms. The early scar contains primarily type III fibers, but is replaced by type I fibers by around the tenth day and no longer represents the weakest part of the injury site based on experimental models [7, 15, 16]. The exercises should be relatively pain-free to avoid tearing the scar tissue bridge and proceeded by an active warm-up to reduce muscle viscosity, improve neural pathways, and improve elasticity.

The predominant strengthening exercises in the early repair phase consist of open kinetic chain exercises with isometric and multi-angled isometrics including quadriceps sets, multidirectional straight leg raises (SLR), and short arc knee extension with light to no resistance (Fig. 11.1a–c). The inclusion of resistance and closed kinetic chain exercises may be initiated when there is good volitional quadriceps contraction without evidence of a quadriceps extensor lag performing a straight leg raise and/or signs of an antalgic gait pattern [11]. Based on the size and severity of the injury, closed chain exercises may be started with partial weight bearing in limited ranges (leg press, shuttle) and progress to full weight bearing through full range (step-ups, squats). From the mid- to late repair phases, there is overlap between the repair and remodeling phases. It is at this juncture that larger controlled stresses can be placed across the injured muscle to help remodel the scar and improve the contractile strength of the regenerated muscle tissue. Exercises in this phase may include concentric and eccentric heel taps, lunges, sport cord resisted directional walking, BOSU ball squats, resisted kicking, and submaximal isokinetic knee extension (Fig. 11.2a–e). The continuation of variable resistance open kinetic chain quadriceps strengthening should continue as the specificity of open chain kinetic quadriceps exercises has been proven to have greater training effects in restoring quadriceps strength in anterior cruciate

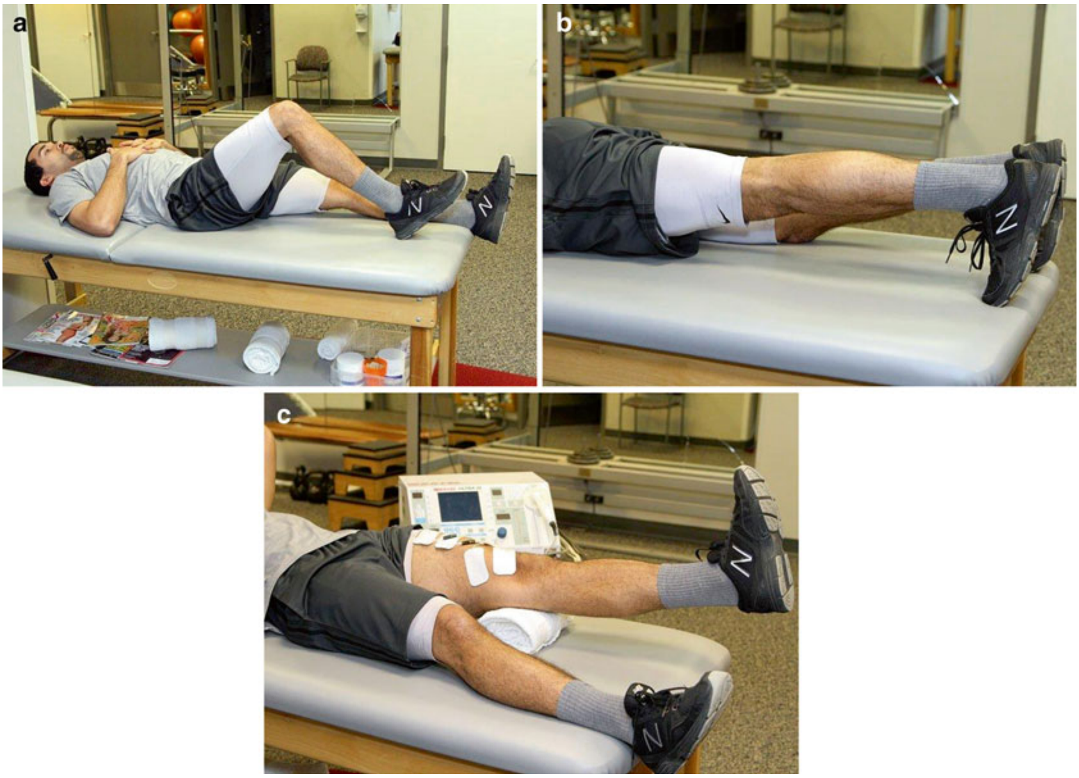

Fig. 11.1 (**a**) Heel slide. (**b**) Prone quadriceps set. (**c**) NMES: short arc quadriceps

ligament (ACL) protocols compared to closed kinetic chain exercises [17].

Particular attention to form is necessary while the athlete performs exercises to avoid compensatory or substitution patterns, such as excessive hip flexion, pelvic drop, or knee valgus due to either pain or weakness in the quadriceps and proximal hip muscles.

It is also during the mid- to late repair phase where manual therapy techniques may be implemented to help realign the healing tissue and avoid restrictions of the muscle scar and connective tissue near the injury site. The incorporation of manual therapy such as cross-friction massage, instrumented techniques with Graston, PNF contract/relax, and static passive stretching will help remodel the scar tissue and restore tensile properties of the muscle (Fig. 11.3). The goals to progress to the next phase are achieving near-full pain-free ROM with passive knee flexion, good proprioception and neuromuscular control of the lower extremities and core, and no significant observable strength deficits during functional testing (squats, step downs).

The inclusion of core exercises is important in the subacute phase and later phase of rehabilitation, as studies have shown a decreased incidence of lower extremity (thigh/groin) injuries in athletes participating in Australian rules football completing a preseason core training using real-time ultrasound while performing neuromuscular control exercises. The exercises were designed to target the transverse abdominis and multifidus while performing various postures and movement patterns. Those players participating in the program demonstrated an increased cross-sectional area of the targeted muscles measured through ultrasound and missed fewer games due to injuries than the control group [18, 19]. It is postulated that with fatigue of the core muscles, altered neuromuscular control leads to fatigue and increased stress/strain to the lower extremity

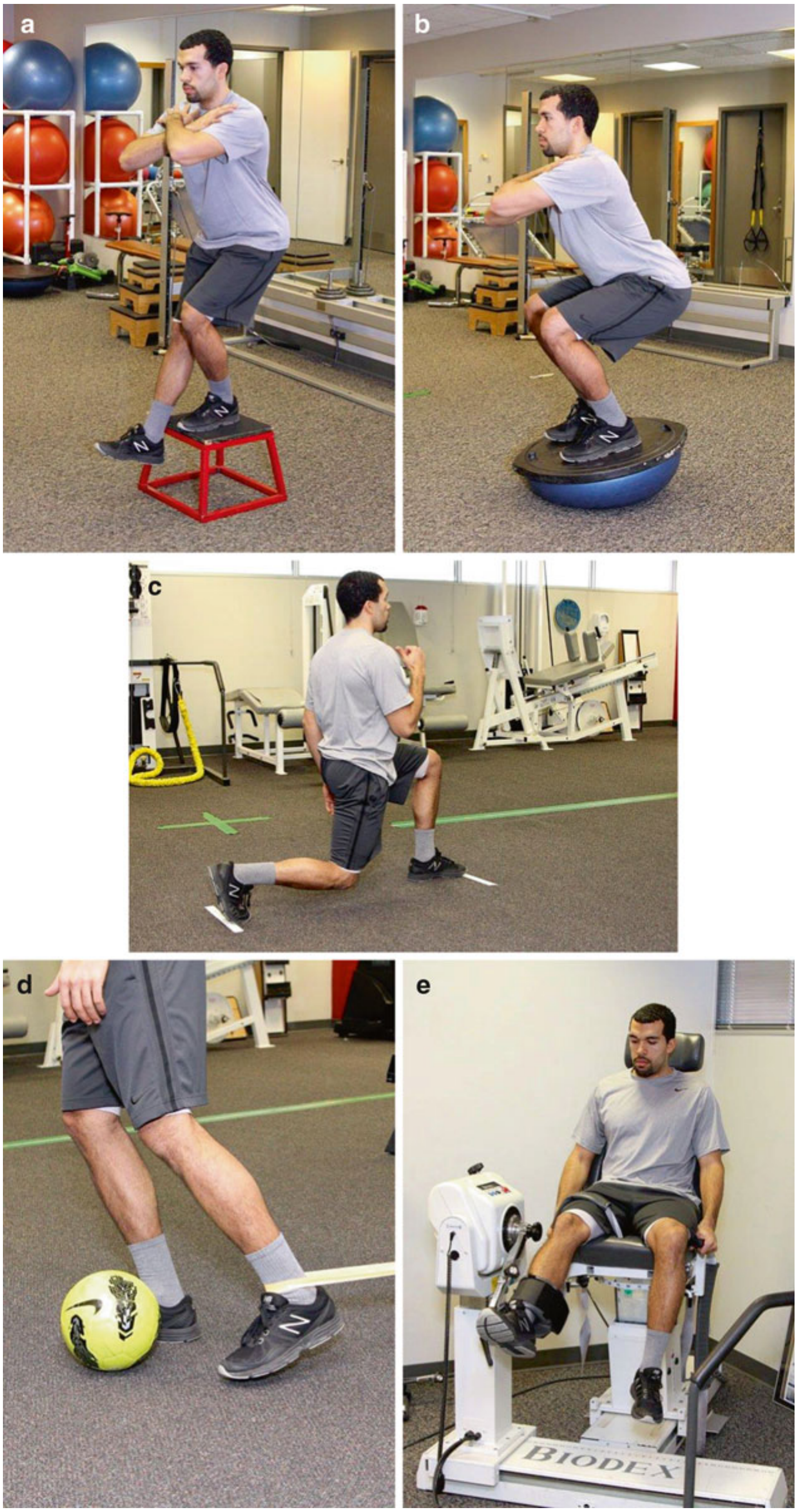

Fig. 11.2 (**a**) Heel taps. (**b**) BOSU squats. (**c**) Lunge. (**d**) Resisted kicking. (**e**) Isokinetic knee extension/flexion

Fig. 11.3 Soft-tissue technique

muscles, especially those muscles with attachment to the pelvis [18, 19]. The inclusion of core exercises will assist in the recovery and help prevent lower extremity injuries [20, 21]. The trunk (core) muscles serve as a foundation for movement, acting in both a stabilizer role through local stabilizer muscles (transverse abdominis, multifidus, internal obliques) as well as a global role with the transference of forces through muscles of the trunk (rectus abdominis, iliocostalis) with integrated kinetic chain activities such as running and kicking [21]. The mechanics of kicking a ball while playing soccer, for instance, increases the internal movement of the quadriceps when the torso is inclined backwards and shifted laterally to the plant leg, while the kicking leg hip generates force through the hip and quadriceps. Engagement of the core muscles (transverse abdominis, multifidus, quadratus lumborum) helps to offset the potential strain caused by these high generating forces in the distal segments [1, 9, 14, 20–23].

Incorporating exercises such as abdominal bracing in both static and dynamic postures has shown to have higher EMG (electromyographic) values for the deep abdominal stabilizers than some other dynamic trunk flexion exercises such as sit-ups and curl-ups and so would be advantageous to incorporate the maneuver into exercises and training to help offset some of the potential deleterious forces to the quadriceps with sporting activities [1, 17, 24]. Other EMG studies have quantified percentage values for some of the traditional stabilization exercises targeting

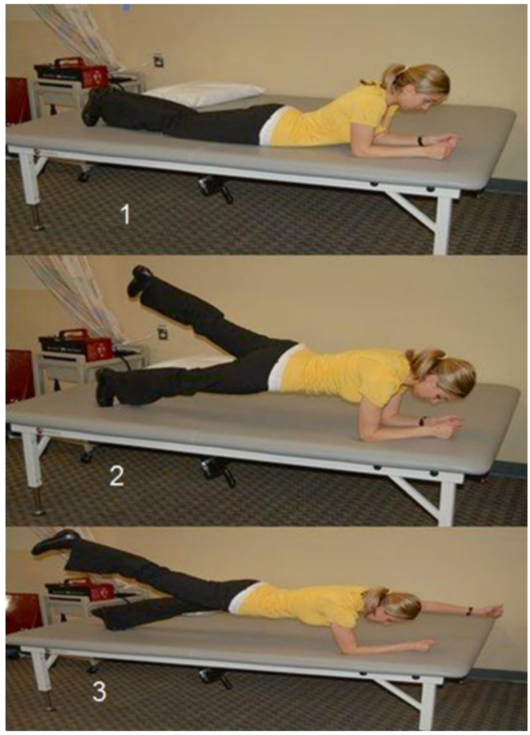

Fig. 11.4 Plank with alternating arm and leg

the multifidus and longissimus and found high-percentage maximum value isometric contraction (MVIC) values for prone lumbar extension to end range with applied resistance [22, 23], and a study using wire-inserted EMG found highest percentage activation of the transverse abdominis with alternating arm and leg from plank position [25] (Fig. 11.4).

Likewise, the hip muscles serve an (gluteus medius and maximus) important role with lower extremity stability and control. Studies have shown that a decrease in gluteus strength and activation patterns lead to suboptimal performance and alignment of the distal lower extremity, with increased knee valgus, femoral adduction, and internal rotation associated with various musculoskeletal disorders such as iliotibial band syndrome and patella-femoral pain [20, 23, 26]. The inclusion of gluteal exercises as part of the quadriceps rehabilitation should be integrated to optimize the function of the lower extremities with higher-level muscle demands and reduce the risk of suboptimal performance and risk of reinjury [20, 23]. Some exercises have been shown to have higher percentage activation targeting the hip abductors (gluteus medius/minimus) and hip extensors (gluteus maximus). A study by Boren et al. [27] analyzing percentage of MVIC for common exercises found the front plank with hip extension, side plank with hip abduction, and single-leg squat to have the highest combined activation of the gluteus medius and maximus out of 22 commonly prescribed hip exercises. Therefore, these high-value combined gluteal exercises should be considered as part of the quadriceps rehabilitation program to ensure kinetic chain restoration.

Remodeling Phase: 7 Weeks to 3 Months

The remodeling phase focuses on restoring full tensile strength, power, ROM, and endurance in the involved leg with a progression to more sport-specific exercises. The inclusion of higher-level exercises such as plyometrics, variable-speed eccentrics, and jump and landing exercises that are closely aligned to the physical demands of the quadriceps in sport. The incorporation of eccentric exercises is fundamental and has consistently been shown to increase the development of optimum length tension in the knee extensors [1, 28]. Functionally, the quadriceps is utilized frequently in an eccentric manner in sports to decelerate, as in the case of changing speed and direction and with the plant leg during an approach to kick a ball. Most quadriceps injuries are also thought to occur with eccentric movements during deceleration [1, 29, 30]. Therefore, it is imperative to incorporate eccentrics into the remodeling phase to prepare the muscle for return-to-play activities [1, 6, 9, 18]. Some of the exercises included in this phase are shuttle jumps, directional jumping, box jumps, reverse Nordic, sport cord deceleration, reverse lunges, pistol squats, and resisted side hops (Fig. 11.5a–f). A study by Brughelli et al. [31] showed a 6.5° shift in the knee extensors with a 4-week supplemental eccentric training program and no incidence of injury compared to a control group where there were incidences of central tendon injuries in soccer. The ability of the quadriceps to have an adaptive response has been shown to occur with eccentric training, whereby an initial drop in peak torque and delayed soreness was followed by a shift in the optimum angle after only the first bout of exercise [28]. Although there are not any eccentric protocols in the literature, it has been recommended that volume and intensity of eccentric exercises be incorporated gradually to avoid injuring the muscle. Delayed onset muscle soreness, which is common following eccentric exercises, should not persist for more than 1–2 days [11, 32, 33]. It is also recommended that eccentric exercises be performed at the end of the session due to the neuromuscular and strength impairments that occur immediately afterwards [1, 32].

The goals at the end of the remodeling phase to begin field drills with return to play are full painless flexion ROM and muscle flexibility and symmetrical quadriceps strength and power [1, 9, 18].

Functional Return to Sport

Although there are no established criteria for return to sport following a muscle injury, with most of the supporting evidence being expert opinion [9, 34], there are some general guidelines. The guidelines include pain-free ROM and near-normal strength (isokinetic testing) preceded by good performance on field or functional performance tests [9]. Due to the frequent involvement of the rectus femoris with quadriceps injuries as well as the biarticular function as a hip flexor and knee extensor, strength and ROM testing for knee extension should then be done both with the hip flexed (in sitting) and the hip extended position in prone, if the rectus femoris is involved (Fig. 11.6). If available, the use of isokinetic testing can provide invaluable clinical objective measures to support performance on field tests. Isokinetic quadriceps strength has been shown to have a high correlation with single jump for distance [35]. Schmitt et al. [36] analyzed isometric quadriceps femoris strength for individuals returning to sport following ACL rehabilitation protocol. They found those individuals whose

Fig. 11.5 (**a**) Shuttle jumps. (**b**) Box jumps. (**c**) Reverse Nordic. (**d**) Sport cord deceleration. (**e**) Pistol squat. (**f**) Resisted lateral hops

quadriceps deficit was greater than 15 % of the control leg performed worse during functional hop tests, which translated to worse self-reported functional measures than those athletes with less than 10 % deficits who performed well on functional field tests. Having knowledge of intrinsic risk factors to quadriceps injury such as a history of previous muscle injury or decreased quadriceps flexibility will allow the residual deficits to be addressed prior to initiating functional return-to-sport activities. A prospective cohort study by Haaglund et al. [37] found intrinsic factors such

Fig. 11.6 Prone resisted knee extension

as previous muscle injury increased the risk of reinjury threefold in soccer teams over a 9-year span. Additionally, having a previous injury to a different lower extremity muscle group increased the rate of injury to the quadriceps and calf muscles due to altered biomechanics of running.

An example of a successful return-to-play protocol following muscle injury has been carried out by Cross et al. [5] based on the physical demands of the sport. The study incorporated a four-stage running program for return-to-play Australian rules football. A player started *stage one* of the program when he was able to perform three sets of 10 single-leg hops pain-free and able to achieve full passive pain-free knee flexion in prone. Stage one of the protocol commenced with jogging for 10 min. *Stage two* initiated striding intervals at 40–60 % maximum intensity. Stage three progressed to sprinting at 90 % intensity for the middle 30 m in an 80-m interval. *Stage three* also incorporated an interval kicking program that started with using a lighter weight ball at shorter distances and progressed to a heavier ball for longer distances. In stage four, sport-specific running drills were initiated that included directional changes, explosive starting and quick stopping with shuttle drills, and figure-eight drills incorporating kicking the ball with direction changes. The player was able to return to team training having successfully completed the program. The return-to-sport guidelines and protocol should be adapted to match the physical demands of the sport and be performed in a relatively pain-free manner. The variability of the functional demands on the quadriceps muscle in sport may be great. When comparing the power and strength demands of the offensive lineman playing American football to the soccer player, where endurance and the eccentric function of the quadriceps will play a much larger role, and so functional measures should be tailored accordingly.

Rehabilitation Following Extensor Mechanism Disruption

Extensor mechanism injuries are relatively uncommon in sports. A study of NFL (National Football League) players documented 14 cases over a 10-year period [38].

Early surgical repair following injury has been shown to have better associated outcomes with the general population in terms of strength, ROM, and function [39–42].

Retrospective studies analyzing protocols where restricted weight bearing and the use of bracing past 6 weeks have shown persistent functional quadriceps strength deficits greater than 20 % 2 years post surgery [42–46]. The key findings of the majority of studies are that early surgical intervention yields the best outcomes, and there is no increased risk with following a more aggressive protocol to start functional strengthening with early full weight bearing versus partial weight bearing in a brace. However, the progression of the athlete's protocol is ultimately at the discretion of the acting surgeon, whose intimate knowledge of technique and tissue quality will guide the appropriate forces to be applied at the correct intervals to assure the best outcomes [40, 41, 44].

Early mobilization following extensor tendon repairs (patellar and quadriceps tendon) has been recommended to avoid the deleterious effects of prolonged immobility, including muscle atrophy, poor cartilage nutrition, decreased patellar mobility, and decreased activation of the quadriceps muscle [40, 41]. Protocols (Table 11.2) allowing earlier progressive ROM and weight bearing have been shown to respond favorably without

Table 11.2 Rehabilitation guidelines following extensor tendon repair

Phase	Modalities	Therex	Ambulation	Manual therapy	Functional exercise
(0–6 weeks)	Modalities for pain (US, cryotherapy) NMES (E-stim)	OKC: Q-sets SLR (brace) Hip strength A/AAROM	WBAT in brace locked in extension	Gentle p-mobs (med/lat → sup/inf)	Gait training
(6–12 weeks)	NMES: quadriceps activation; cryotherapy as needed for effusion	PREs: OKC/CKC core-strengthening proprioceptive	Normalize gait pattern	CF scar massage, Graston, P-mobs; PROM Restore full PROM	Closed chain exercises with good volitional quad: step-ups, leg press, lunges
(12–24 weeks)	PRN modalities	PREs: isotonic, isokinetic *SL emphasis	Conditioning: jogging, bike, elliptical	Cross-friction; Graston; contraction/relaxation	Quad eccentrics, plyometrics
Return sport (6–9 months)		WNL strength: isokinetic functional exercises	Interval running, sprinting	WNLs PROM quadriceps	Sport-specific exercises without pain

*Emphasizing importance of pain free Rom

increasing the risk for reinjuring the repaired tendon [40, 41]. This in part has been attributed to surgical technique with the use of suture augmentation allowing for controlled stress to be placed across the knee without placing undue stress on the repair site [26, 40, 41]. The rehabilitation program generally consists of four phases.

Phase I

In *Phase I* the goals are pain control, restoring volitional quadriceps and increasing flexion ROM within prescribed guidelines by the physician with AROM, AAROM, and PROM (passive range of motion). The athlete is permitted weight bearing as tolerated (WBAT) with the knee brace locked in extension. Strengthening consists of submaximal quadriceps sets and multi-angle hip exercises with the knee brace in extension. The use of neuromuscular electrical stimulation (NMES) may also be initiated to assist with restoring volitional quadriceps to prevent arthrogenic muscular inhibition (AMI) and long-term delayed quadriceps strength as a common sequelae to extensor tendon surgery [14, 40–42, 44–46].

Phase II: 6–12 Weeks

Phase II commences with discontinuation of the knee brace when good volitional quadriceps is evident without signs of an extensor lag. Emphasis should also be placed on normalizing gait parameters without evidence of reactive joint effusion or compensations. It is also at this juncture that open and closed chain quadriceps exercises are initiated and progressed according to the patient response including partial squats, leg press, step-ups, submaximal open and closed chain knee extension, and single-leg balance exercises [40, 41, 46]. Core and hip exercises should also be progressed to integrate the closed chain function of the leg. Cardiovascular exercise at week 10 may be implemented, including stationary biking, elliptical training, and treadmill walking. Manual therapy techniques should be used and are necessary to assist with aligning scar tissue and restoring patellar mobility and flexion ROM with the use of cross-friction massage and patellar mobilizations, to restore full pain-free ROM. The goals of Phase II are for the athlete to have good volitional quadriceps strength, full passive knee flexion, and normal strength in all other lower extremity hip and core musculature and demonstrate good proprioception and quadriceps control with single-leg balance [38, 40, 44, 46].

Phase III: 12–24 Weeks

Exercises are progressed with single-leg closed kinetic chain resistance and proprioceptive exercises without evidence of reactive patella-femoral pain or effusion. Exercises such as pistol squats, lunges, shuttle jumps, and eccentric exercises may be incorporated into the advanced stage of strengthening progressing to sport-specific activities such as running and agility drills. The continuation of open chain quadriceps exercises to target isolated quadriceps strengthening should be performed, including isotonic, elastic, and isokinetic resistance. Criteria to begin higher-level exercises such as jogging and submaximal agility drills include the ability to perform 20 single-leg squats with good mechanics, achieving full isometric quadriceps strength, and the performance of 10 single-leg hops maintaining good alignment and control.

Functional Return to Sport

Return-to-sport-specific drills and activities require the athlete to achieve near-normal strength in the quadriceps (85 % of involved leg) and good performance on functional tests that have been correlated with clinical measures including the single-leg hop test for distance, single-leg crossover hop test, and 6-m timed hop tests [35, 40, 44, 46].

Summary

Quadriceps muscle injuries occur frequently in sports with contusions during contact sports and strains/tears in sports involving sprinting, jumping, and kicking where the mechanism of injury is usually caused by an eccentric overload to the muscle. Rehabilitation protocols should follow the principles of biologic healing of the muscle tissue to allow adequate recovery while placing appropriate stresses at regular intervals in order for the muscle to return to full functional strength. Although there are no standard protocols in the literature, the progression of exercises should remain relatively pain-free, progressive in nature, and be specific to the demands of the sport in the later phases of rehabilitation. Functional field tests are initiated when adequate strength, ROM, and flexibility goals have been achieved. The incidence of extensor tendon injuries is relatively uncommon in sports when compared to frequency of occurrence of quadriceps muscle injuries. Early surgical intervention has been shown to have the better functional outcomes, but it is reported that nearly half of the athletes return to the same level of competitive play following surgical repair due to persistent deficits. Certain surgical techniques (suture augmentation) have been shown to allow earlier motion and weight bearing, which improves functional outcome without risking the deleterious immobility and limited weight bearing. The rehabilitation protocol for extensor tendon injuries lasts approximately 6–9 months, with return to play initiated when the athlete achieves clinical benchmarks and performs well on functional field tests designed to be specific to the sport.

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Hamstring Injury Rehabilitation and Injury Prevention

12

Dave Kohlrieser

Introduction/Etiology

Hamstring injuries are common pathologies in those participating in sports involving high-speed skilled movements, especially in sports including jumping, hurdling, and kicking. Epidemiological data indicate that the incidence of hamstring strain injuries in sports is increasing over the past two decades [1]. Hamstring muscle strains account for 26 % of all injuries sustained in track and field events, with the majority occurring during sprinting and hurdling events [2]. It is reported that hamstring strains account for 13–15 % of all injuries and when compared to other injures are responsible for most time lost in Australian rules football [1, 3]. These injuries also account for 12–14 % of all injuries occurring in soccer [1]. Such injuries can lead to prolonged symptoms, decreased level of performance, and significant time lost from sport. When compared to other injuries, hamstring injuries are responsible for most time lost in Australian rules football [3]. While previous injury is a risk factor for several musculoskeletal injuries, hamstring injuries in particular demonstrate a high risk for re-injury. It has been shown that one-third of those who suffer a hamstring injury will re-injure their hamstring, with majority of these reoccurrences occurring within the first 2 weeks of returning to sport [4]. Re-injury rates have been reported as high as 16 % in soccer and 32 % in Australian rules football [1, 5, 6]. There remains an elevated risk even after this early period of returning to sport. In Danish professional soccer, it is reported that 25 % of all players who sustain a hamstring injury will have a recurrent injury during the following season [7].

Risk Factors

Previous Injury

History of a previous hamstring injury has been shown to be the strongest risk factor of hamstring injury [8], with the greatest risk during the initial 2 weeks following return to sport [9]. Evidence linking decreased hamstring strength to injury is conflicting [1, 10, 11]; however, residual hamstring weakness after primary injury may be a secondary risk factor. Several studies have demonstrated persistent weakness throughout the hamstrings after what was believed to be a full recovery from a previous injury. Isometric knee flexion strength was found to be significantly reduced in sprinters with previously injured lower extremities [10]. Additionally, preseason isokinetic testing was performed on Australian rules football players and found that those with previous hamstring injuries produced lower peak

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concentric hamstring torque when compared to those without history of injury [11]. However, this finding was not supported by a similar study completed by Bennell et al. [12]. Even with conflicting results, a thorough assessment of strength should be performed on any athlete with previous history of injury to ensure any strength deficits or asymmetries are identified and addressed.

Other lower extremity muscular imbalances, specifically hamstring strength asymmetry between the lower extremities, poor hamstring: quadriceps strength ratio, and poor gluteal/core strength or stability, have been found to be associated with hamstring injuries.

Hamstring Strength Asymmetry Between Lower Extremities

Hamstring strength asymmetry between the lower extremities has been proposed to increase the risk of a hamstring injury on the weaker leg. For this reason, it has been recommended that between-leg comparisons of strength are more meaningful clinical measures of weakness than comparisons made to a group average or standardized scores [1]. Hamstring strength differences of greater than 10 % between lower extremities were found to be predictive of hamstring injury in football and track and field athletes [1, 5, 13]. Hamstring strength asymmetry of ≥8 % in Australian football players and ≥15 % in soccer players was found to have an increased risk for injury [1, 11, 14].

Hamstring:Quadriceps Strength Ratio

Strength testing comparing the hamstrings to quadriceps, termed the hamstring:quadriceps strength ratio, can provide the clinician with valuable information regarding muscular imbalance at the knee and possible increased risk for injury or re-injury. A lower hamstring-to-quadriceps strength ratio suggests a decreased ability of the hamstrings to slow down the flexing hip and extending knee joints during the terminal swing phase of running. The powerful contraction of the quadriceps during the early swing phase of running gait may potentially produce angular momentum at the knee joint that overloads or exceeds the capabilities of a weakened hamstring complex [1, 15]. Research on the hamstring:quadriceps strength ratios initially focused on concentric strength comparisons, neglecting the eccentric hamstring function during terminal swing phase running [1]. Further research comparing eccentric hamstring strength to concentric quadriceps strength more closely reflects the function of these muscle groups during running [1, 12, 16]. Associations between strength ratios and hamstring injuries are hard to determine due to limitations of many of the studies. One powerful study that analyzed the association between hamstring-to-quadriceps strength ratio and hamstring injuries in soccer players showed that those with hamstring:quadriceps concentric strength ratio below 0.45–0.47 and a hamstring:quadriceps eccentric strength ratio below 0.80–0.89 had significantly greater frequency of injuries than those without imbalances [1, 14]. These findings support that identifying and correcting abnormal strength ratios may protect athletes from future hamstring injuries [1].

Decreased Gluteal and Core Musculature Strength

Several articles site core instability and hip weakness as a risk factor for lower extremity injury [17–19]. More specifically, deficits in core stability have been associated with increased risk of hamstring injury [20–23]. It has been theorized that poor control of the lumbopelvic region would prevent an athlete from keeping the hamstrings at safer lengths and under safer loads during sport-specific movements, thus increasing their risk of injury [22]. In addition, strength and/or activation deficits of the gluteus maximus muscle, having similar actions to the hamstring muscles during running, have been proposed to place greater demand on the hamstring muscles, potentially predisposing them to injury [24]. A systematic review of hamstring risk factors determined that athletes who had undergone an agility and stabilization training program were at 7.7 % risk of injury versus 70 % risk without stability training [25].

Other potential risk factors beyond strength deficits and previous history of hamstring injury have been identified and reported. Older age and increased quadriceps flexibility were found to significantly increase an athlete's risk for hamstring injury in Australian rules football. In the study performed by Gabbe et al. in 2005, athletes over the age of 23 were found to be almost four times more likely to suffer a hamstring injury than the younger players. The authors also reported that increased quadriceps flexibility, as determined by greater than 51° of knee flexion when in the modified Thomas test position, also increased the risk for sustaining a hamstring strain in athletes [26]. Previous posterior thigh or knee injury, being of aboriginal descent, and history of osteitis pubis were all factors that were found to increase the risk of hamstring injury in Australian rules football players. This study also supported older age as a potential risk factor for injury. A reported history of previous back injury was not correlated with an increased risk for hamstring injury on magnetic resonance imaging (MRI), but was found to increase risk for pain referred to the posterior thigh [27].

Non-operative Rehabilitation

Phase I

Initial management of an acute hamstring strain favors conservative measures including rehabilitation. The goal of the rehabilitation program is to return the individual or athlete to their prior level of sport or activity level while minimizing risk of re-injury. Due to the high re-injury rates after rehabilitation and return to sport, there remains much speculation regarding the effectiveness of commonly used treatment approaches for hamstring injuries [9]. These rates indicate the need for clinicians to use more objective criteria in order to progress an athlete through each phase of rehabilitation [24].

Acute Phase

The focus of the immediate post-injury phase of rehab is to reduce pain and edema while protecting scar formation [9, 24]. Experimental research suggests that 3–4 days of immobilization after an acute hamstring strain can prevent excessive scar tissue formation while mobilization occurring too early may increase scarring, causing further tissue damage [28]. The importance of early protection of the injured area should be stressed ensuring that excessive stretching of the injured hamstrings will be avoided. Excessive stretching in this acute phase can result in dense scar formation prohibiting muscle regeneration [29]. Range of motion should be encouraged but limited to pain-free ranges during this early period. The individual should be instructed to ambulate with shorter strides in order to limit pain and/or stretching of the hamstrings during gait. The use of crutches is only necessary in severe cases. It is important to instruct the individual not to actively hold their injured knee in flexion if using crutches, as this can place excessive loads through the injured hamstrings. The individual can return to a normalized gait pattern once pain allows [9].

The patient should be instructed to use ice at the injury site 2–3 times a day for pain and inflammation management. The duration of icing is dependent on type of application. If an ice cup is used, the duration should be no more than 3–5 min. However, if an ice pack is used the individual should keep the pack in place for 15–20 min [30]. More research is needed, but early studies show that cold water immersion, performed without active or passive movement for 2–3 days after injury, may be beneficial after acute muscle strains [24, 31].

Non-steroidal anti-inflammatory drugs (NSAIDs) can also be used during the acute period. There is some controversy with the recommendation of NSAID use in this early period due to reports that use of these medications may have no benefit and may negatively affect muscle function after recovery [32, 33]. As an alternative, analgesics such as acetaminophen have been suggested [9, 34].

Therapeutic exercises can be initiated in this early phase, but should be limited to very low intensity pain-free exercises involving the entire lower extremity and lumbopelvic region. Sacroiliac joint manipulation may be indicated if functional leg asymmetries exist to help restore normal lumbopelvic position [24]. The purpose of early exercise is to limit the amount of atrophy in the region and maintain and/or develop neuromuscular control [9]. Exercises in this early phase are not limited to but can include stationary bike with low resistance, single-leg balance, and side stepping. Isolated resistance exercises of the injured hamstring musculature should be avoided in the early post-injury period [9].

The individual should be closely monitored during rehabilitation, and caution should be taken to avoid progressing the athlete too quickly. As the patient's pain and inflammation resolve, the clinician should determine readiness for progression to the next phase of the rehab program. Heiderscheit et al. recommended the following criteria to progress: (1) normalized pain-free gait pattern, (2) ability to tolerate very low-speed jogging without pain, (3) pain-free isometric contraction of hamstrings tested in prone position with knee flexed to 90° [9].

Phase II

The goals of the subacute phase are to achieve full strength in midrange positions, full pain-free range of motion, and to correct muscle imbalances and/or neuromuscular control deficits that may have contributed to the athlete's initial injury [24]. The intensity of the range-of-motion exercises are increased per the individual's tolerance and pain response. Strengthening near end-ranges of motion should be avoided if weakness remains, as musculotendinous unit may not be able to guard against passive lengthening and could limit or negatively affect healing and repair [9, 28]. The use of NSAIDs during this phase is not typically recommended due to their ability to mask pain. This can result in overly aggressive exercise as the patient may not accurately be able to self-assess pain response [9].

To improve hamstring strength, a progression from multi-angle isometrics to concentric and finally toward eccentric strengthening is recommended. Caution should be given to performing repeated concentric hamstring exercises at shortened muscle lengths. Evidence shows that this type of training can lead to shorter optimal length/tension relationship of a muscle [24, 35, 36]. Lower level eccentric strengthening exercises for the hamstring musculature are also initiated during this phase [9, 28]. Low-level eccentric exercises are essential in this phase because eccentric strengthening has been the only intervention shown to consistently increase the length/tension relationship and decrease injury rates after hamstring injury. Submaximal eccentric strengthening exercises should be initiated in midrange positions during functional movements rather than isolated hamstring exercises.

Fig. 12.1 Slump test

Flexibility and stretching exercises are commonly included in the rehabilitation programs after acute hamstring strains due to athletes presenting with reduced range of motion after injury [9, 20]; however, the benefits of flexibility and stretching for injury prevention and recovery remain relatively unknown [37]. Heiderscheit et al. recommended including the active slump test in the clinical examination [9] (Fig. 12.1). If a positive active slump test is present, it is recommended to include neural mobilization techniques in the rehabilitation program [9, 38]. Kornburg and Lew demonstrated that including the slump stretch in individuals with a grade I hamstring strain and a positive active slump test significantly reduced their time away from sport [39]. The effect of including neural mobilization techniques in those with more severe injuries has not been reported in the literature [9].

Limitations in hip flexor mobility should also be identified and addressed if present. Athletes with decreased hip extension mobility have been shown to compensate by increasing the amount of anterior pelvic tilt and lumbar extension during functional activities. This common compensation can potentially increase the length of the activated hamstring muscles during running and thus increase the risk of injury [20, 24, 26, 40].

Low-level agility exercises may be initiated during this phase of rehabilitation. The speed and intensity of exercises should be cautiously increased over time, with speed being progressed first. Exercises should initially focus on movements in the transverse and frontal planes. The individual can gradually be introduced to movements in the sagittal plane per pain response, being cautious not to overstretch the injured tissue. The clinician should begin to prepare the individual for return to recreational or sport participation during this phase. Examples of exercises that can be included are side shuffling, supine bridges with feet walkouts, rotating body bridges/planks, and lunge walking with trunk rotations [9]. Sport skills can be initiated as long as end-range lengthening of the hamstring musculature is avoided. Running speed is typically limited to 50 % of the athlete's maximal running speed. Heiderscheit et al. reported that normal range of motion can be restored through the use of appropriate functional exercises and the reduction of pain and edema without the use of specific stretching of the hamstrings [9].

Sherry and Best compared the effectiveness of two different rehabilitation protocols for acute hamstring injuries. The authors analyzed the time needed to return to sport and re-injury rate during the first 2 weeks and throughout the first year after returning to sport. The results indicated that a rehab program including progressive agility and trunk stabilization exercise is more effective than a program emphasizing isolated hamstring flexibility and strengthening exercises for return to sports and re-injury prevention in those after an acute hamstring injury [22]. In addition, EMG studies have shown that the timing and activation patterns of the gluteus maximus and the hamstring muscles during running are similar [24, 40, 41]. Therefore, any deficiency in gluteus maximus strength and/or activation may place increased demands on the hamstring complex, increasing risk for an overuse injury [24]. More recent rehabilitation programs have been incorporating gluteus maximus activation and progressive strengthening such as double-leg to single-leg bridging and finally reintroducing gluteus maximus with hamstrings in exercises such as lunges and single-leg dead lifts [24, 42].

To progress an individual to the next phase of rehab, it is recommended that the individual meets the following criteria: (1) 5/5 hamstring strength with manual muscle testing when in prone position with knee at 90° of flexion [9] and pain-free resistive strength testing when in prone with 15° of knee flexion with <10 % deficit bilaterally; (2) negative slump test; (3) active knee extension test <10 % asymmetry and <20° of knee flexion; (4) modified Thomas test >5° and symmetrical to opposite extremity [24]; (5) ability to jog forward and backward at 50 % maximal speed without experiencing pain [9].

Phase III

The emphasis of the final phase of the rehabilitation program should be on preparing and returning the individual to the specific demands of their sport or desired activities. This phase should include more intense and aggressive sport-specific movements through full ranges of motion necessary for sport participation [9]. There are no range-of-motion restrictions during exercise as the individual should possess sufficient strength without pain. Therapeutic exercise should emphasize sport-specific movement patterns including change in direction and technical skills. The intensity of the trunk stabilization exercises should be progressed to include transverse plane motions and asymmetrical postures. Eccentric strengthening should be progressed to include end-range positions with gradually increasing resistance. Explosive acceleration and sprinting should be avoided and only included in rehabilitation program once athlete passes all return-to-sport criteria. [9]. See "Return-to-Sport Criteria and Testing" section regarding safe clearance of individual back to sport or recreational activities.

Postoperative Rehabilitation

Surgical repair is considered the best option for acute hamstring ruptures [43]. This procedure has been reported to significantly improve the prognosis of those suffering a proximal hamstring rupture, but could affect their ability to return to previous activity level and sports, making the postoperative rehabilitation critically important [44]. The ultimate goal of surgical repair and the rehabilitation program is to return the patient to their prior level of activity as quickly as possible while minimizing the risk for re-injury [45]. There is little consistency between rehabilitation protocols following proximal hamstring tendon repairs, and there have been no multicenter randomized controlled trials comparing different guidelines published [45].

Preoperative care should include patient education and exercises to limit atrophy to surrounding musculature. The patient should be educated on the injury, upcoming surgical procedure, and the recovery/rehabilitation protocol. The patient should also be fit and educated on the proper use of axial crutches. There is no need for a preoperative brace, and the patient should be instructed not to attempt to stretch or strengthen the injured hamstring as this will increase reactivity at the proximal hamstring tendon and ischial tuberosity. It is recommended that the only exercises to be included in this period are gluteal and quadriceps isometrics to limit atrophy in these muscle groups [45].

Immediate Postoperative Period

Typically patients are not braced or immobilized after surgical repair as long as they can maintain a neutral position of the leg in order to limit excessive tension through the repaired tissue or surgical incision. There are no consistent recommendations between surgeons as far as the use of postoperative bracing. Askling et al. reported that no brace is necessary after surgery while Lefevre et al. recommended that patients to be immobilized by a simple splint with the hip in 30° of flexion [44, 45]. The patient should be instructed to use bilateral axial crutches in order to limit loading and force through the involved lower extremity. It is recommended that patients use crutches for 2 weeks in their home and for 5 weeks for community ambulation. Upon leaving the hospital it is also recommended that the patient be provided with toilet and bed elevation, high chair cushion, and long clutching tongs to prevent excessive tension through repaired hamstring during activities of daily living and self-care [45].

Week 1

During this early protective phase, the hamstring muscle group should be kept in a shortened and relaxed position to avoid excessive strain or tension on the repair site. The patient should avoid sitting directly on the ischial tuberosity except when using a raised toilet seat. The patient is permitted to be partial or toe-touch weight bearing with bilateral axial crutches at this time [44, 45]. The only exercises recommended during this period are isometric gluteal and quadriceps sets, ankle pumps, and assisted heel slides allowing no more than 30–45° of knee flexion. These exercises should be included in the patients early home exercise program [45].

Weeks 2–3

After the first postoperative week it is recommended that the individual attend formal physical therapy at a frequency of 1–2 times per week. If immobilized postoperatively, the patient would be placed in a custom knee brace allowing full knee flexion but limiting the last 30° of extension [44]. Once the patient can demonstrate 30° of hip flexion during a straight leg raise, the patient is permitted to ambulate weight bearing as tolerated with short step lengths while continuing to use bilateral axial crutches. The patient is instructed to add single-leg balance and progress to mini knee bends while in single-leg stance when able. Other exercises deemed safe during this period include isometric hamstring muscle contractions and passive knee flexion and extension range of motion while in prone position [45].

If the patient is able to complete exercises included in week 2 without increasing pain or reactive effusion, additional exercises may be added. The clinician should monitor the patient closely during and after exercise and should exercise caution with progression or additions of higher level exercises. Exercises that can be added in the third postoperative week are standing hamstring curls, stationary marching on thick pad, and heel raises [45].

Weeks 4–6

Typically, between the fourth and sixth postoperative week the patient may begin to utilize an upright stationary bike to improve range of motion and flexibility [44, 45]. The seat height should be set in a high position allowing the patient to reach 70° of hip flexion with 90° of knee flexion. At this time exercises from the first 3 weeks may be discontinued and more specific lower extremity strengthening exercises may commence. The patient should be monitored to ensure that exercises are performed with correct technique and performed slowly during this period. Isometric hamstring curls while seated and bridges can be added at this time [45].

If postoperative bracing was used, the patient would be permitted to be full weight bearing with full knee range of motion after 6 weeks [44]. At this point in the recovery phase, the emphasis should be on normalizing the patient's gait pattern. Additional exercises including prone isometric hamstring contractions and higher level single-leg balance exercises are also included at this time. The patient can bias the medial or lateral hamstring muscles during prone hamstring isometrics by internally or externally rotating the leg, respectively [45].

Week 7+

Lower extremity strengthening exercises can be progressed during this period. Technique should be monitored and progression of intensity or resistance should be based on patient's tolerance and response to exercise. Suggested lower extremity strengthening exercises include mini squats, step downs, leg press, hip abductor strengthening while standing with use of tubing or machine, and higher level proprioceptive and balance training [46]. Hamstring curls in prone position on a machine can be initiated. The patient should start in prone position then progress to seated hamstring curls with hip positioned in 90° of flexion [46]. Other safe hamstring exercises which maintain the hamstring in midrange positions can be initiated as tolerated and include heel slides, double-leg bridges, and standing leg extensions [47] (Fig. 12.2).

Fig. 12.2 Double-leg bridge

Eccentric strength training is recommended to begin at this time ensuring at least 2 days of rest a week. In order to progress the patient safely, eccentric exercises should begin in midranges and be performed bilaterally. Progressions of eccentric exercises may include single-leg forward leans, single-leg bridge lowering, and assisted Nordic curls [47]. The treating clinician should perform manual strength assessment with the patient in a prone position with the knee and hip extended. This assessment should be performed on a weekly basis to determine progress. As the rehab program progresses, other testing positions should be included to assess for pain and strength deficits. A side-to-side comparison of strength and range of motion is recommended in order to identify impairments and asymmetry. Askling et al. recommend that patients should perform

Fig. 12.3 Single-leg bridge

Fig. 12.4 Forward lunge

2–4 hamstring exercises during each physical therapy or home training session focusing more on quality and control of the movement rather than quantity. Exercise should be monitored and patients should be educated regarding correct technique and form to limit compensatory movements. Patients will often demonstrate gluteus maximus, adductor magnus, and gastrocnemius activation to assist the weakened or dysfunctional hamstrings with hip or knee motion [45].

Between weeks 12 and 16 forward and backward fast walking and cautious light jogging with short strides may be initiated [44]. It is recommended that stationary jogging with high knee lifts be included gradually increasing intensity and duration over time. Bridges should be progressed to single-leg bridges at this time (Fig. 12.3). This exercise can be further progressed by moving the foot farther away from the hip leading to increased knee extension. Pendulums or forward/backward leg swings can be included to improve the flexibility of the hamstrings.

As the patient continues to progress, specific hamstring strengthening exercises should be combined with more complex movements such as lunges, squats, and different low-level plyometrics (Fig. 12.4). Additionally, hamstring strengthening can progress toward higher velocity strengthening in lengthened positions; an example would be weighted single-leg dead lifts [47] (Fig. 12.5).

As the patient's strength, flexibility, and tolerance to higher volumes and intensity of exercise increase, the clinician should begin to include more sport-specific movements or activities.

Fig. 12.5 Single-leg dead lift

During this transition from rehabilitation toward sport participation, the clinician should continue to assess the individual's strength, range of motion, and confidence to ensure safe return to sport. Lefevre et al. recommended that regular sport activities could be started between postoperative weeks 16 and 32 [44]. In addition to general time guidelines, Askling et al. state that patients should demonstrate the ability to complete jumping, running, and cutting activities without pain, stiffness, or feelings of decreased confidence or insecurity before returning to pre-injury sport activities [45]. See "Return-to-Sport Criteria and Testing" section for criteria for RTS progression.

Return-to-Sport Criteria and Testing

Many athletes who complete a rehabilitation program will demonstrate full range of motion and strength as assessed manually clinically.

Fig. 12.6 Isokinetic hamstring testing

Fig. 12.7 End-range position manual muscle test

Fig. 12.8 H test

However the re-injury rate after hamstring strains remains high especially in the first couple weeks of returning to sport [4]. This had led many to question the rehabilitation programs and criteria for returning athletes to sport after hamstring injuries.

As mentioned previously, a decreased length/tension relationship is a potential cause of hamstring injury and re-injury. Thus, Mendiguchia and Brughelli suggest a test for optimum angle of peak torque by testing knee flexion strength isokinetically at 60°/s (Fig. 12.6). Peak knee flexion at <28° and <8° of asymmetry between legs is recommended prior to return to sport [24]. Few clinics have access to an isokinetic strength testing system; thus a more relevant alternative is to perform the manual break test in a position near maximal functional length of the hamstring complex [48]. This test is described by having the patient first pull the hip to their chest while the opposite leg remains extended on the table. The examiner then passively extends the knee until soft tissue restriction is felt. The clinician slightly reduces the amount of tension by flexing the knee 10°. From this position the break test is performed and can be scored on grading scale or measured objectively with dynamometer [48] (Fig. 12.7).

A second clinical test assessing strength with the hamstring in a maximally lengthened position was developed by Askling et al. Termed the "H test," the patient assumes a supine position with the opposite leg stabilized (Fig. 12.8). The athlete then rapidly flexes the hip with the knee maintained in extended position. The amount of hip flexion was compared to passive slow hip flexion range of motion in this straight leg raise position. The patients also rated their "insecurity" during the ballistic straight leg raise on a VAS-scale [49]. Patients who were cleared for return to sport based on standard clinical assessments had deficits in dynamic flexibility during the H test despite having normal passive flexibility. Interestingly, the subjects also reported insecurity on the VAS-scale while performing the test.

There have been no studies completed to establish the validity or reliability of this test [48, 49].

Hip extension strength and lumbar rotation stability are also included in Mendiguchia and Brughelli's return-to-sport algorithm. It is suggested that isokinetic hip extensor strength tested at 60°/s is recommended to show less than 10 % asymmetry between limbs [24]. As athletes return to kicking, sprinting, and agility activities in the phase, it is important to determine the stability of the trunk. The ASLR Test is a screen of lumbar spine stability to assess rotational control of the lumbar spine [24, 50]. During this test, patients lay supine on a table and actively raise their right leg 20 cm above the table while keeping their knee straight holding the position for 5 s [50]. In order to progress beyond this stage, an athlete must be able to perform this without anterior pelvic tilt.

Leg asymmetries in horizontal force production have been found in Australian rules football players with a history of hamstring injury compared to players without previous injury. Potential reasons for this asymmetry may include increased anterior pelvic tilt, which decreases hip extension and/or impaired power transfer during the stance phase [24]. Thus, a functional test assessing leg asymmetries in horizontal force is suggested in the return-to-sport algorithm with less than 20 % difference between limbs on a non-motorized treadmill at 80 % running velocity. Most clinics do not have access to this equipment, thus future research is needed to determine a clinical test to identify asymmetries in horizontal force production between lower extremities.

Injury Prevention

Due to the high and rising incidence of hamstring strain injuries and the high rate of re-injury, the development of effective injury-prevention programs and strategies could have a significant impact for those participating in sports. There have been many studies conducted to aid in identifying potential risk factors associated with initial hamstring injuries and re-injury [8, 9, 26, 51]. There is limited evidence to evaluate or support the effectiveness of preventing hamstring strain injuries [9].

Hamstring flexibility and stretching exercises are commonly used by clinicians during rehabilitation after injury and prior to injury in an attempt to prevent occurrence. The inclusion of a flexibility program has not been shown to decrease the incidence of hamstring injuries [52]. Although decreased quadriceps flexibility has been identified as a risk factor for hamstring strain injuries, the effectiveness of a stretching program targeting this muscle group at reducing hamstring injury rates has not been determined [9].

As previously stated, hamstring injuries are thought to occur during maximal eccentric muscle actions and reduced strength has been shown to be a risk factor for injury. For these reasons, many have recommended the use of an eccentric strength training program to be included in rehabilitation and for injury prevention [52]. Several studies have shown the benefits of including eccentric strengthening in hamstring injury prevention and rehabilitation. Some of the effects reported from eccentric training include an increased optimum angle for concentric force development, improved eccentric force production, and improved muscular flexibility [52, 53]. O'Sullivan et al. completed a systematic review to determine the effects eccentric training has on lower limb flexibility. The results of their review led them to conclude that eccentric training can effectively improve lower limb muscular flexibility. There needs to be further research comparing the flexibility improvements between static stretching programs and the improvements from eccentric strengthening programs [53].

Arnason et al. examined the effect of eccentric strength training and flexibility training on the incidence of hamstring strains in soccer players. Seventeen to thirty elite soccer teams were followed for 4 years using the first 2 years as baseline data. An intervention program consisting of warm-up stretching exercises and/or eccentric strength training were included in the remaining two seasons. The incidence of hamstring strains was lower in the teams that adopted the use of the eccentric training program compared to those that did not. Interestingly, there was no difference

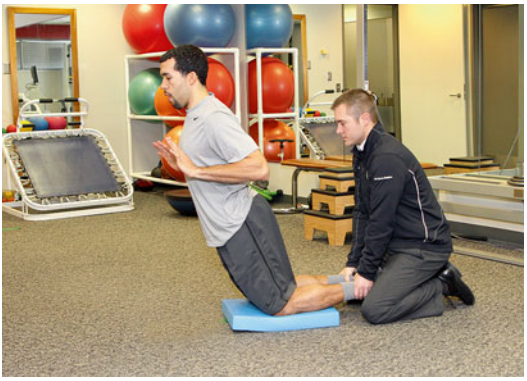

Fig. 12.9 Nordic eccentric hamstring exercise

in the incidence of hamstring injuries between teams that used the flexibility training program and those that did not. The authors reported that these finding indicated that eccentric strengthening by way of Nordic hamstring exercises combined with warm-up stretching routine can reduce the risk of hamstring strains [52].

The Nordic hamstring lowering exercise is a commonly used eccentric strengthening exercise for the hamstring complex (Fig. 12.9). To perform the exercise, the athlete assumes a tall kneeling position with a partner stabilizing their lower legs behind them. The athlete is then instructed to lean forward in a smooth controlled movement while keeping his/her back and hips extended. They are encouraged to lower themselves as slow as possible using their hamstrings to control the descent as long as possible. Once they are unable to maintain control they are instructed to touch down with their hands and lower their chest to the ground. They should forcefully push off ground with arms to limit concentric activity of the hamstrings to return to the tall kneeling starting position [36, 54].

Another study by Peterson et al. examined the preventative effect of the Nordic hamstring eccentric exercises on the rate of acute hamstring injuries in male soccer players. The study included 54 Danish male professional and amateur soccer teams that were divided into an intervention group and a control group. The intervention group consisted of 461 players who received a 10-week progressive eccentric training protocol utilizing the Nordic hamstring exercise followed by a weekly seasonal program. The control group continued to follow their usual training routines. It is important to note that the volume of eccentric exercises was progressive over the 10-week period.

There were 52 acute hamstring injuries in the control group compared to only 15 in the intervention group. These results demonstrate the ability of an eccentric training program to reduce the rate of first-time hamstring strains by >60 %. The study also demonstrated that this specific eccentric program reduced the rate of re-injury or recurrent injuries by approximately 85 %. There was no significant difference in the number of injuries suffered during the early phase of the study, indicating that there is no increased risk from initiating an eccentric strengthening program. The results indicated that the inclusion of the warm-up flexibility exercises was not necessary and that the eccentric program alone resulted in desired effects. The significant reduction in injuries occurred later in the study leading the authors to conclude that several weeks of the training program are necessary to gain the injury-prevention effects [54].

Neuromuscular control training and exercises targeting the lumbopelvic region and lower extremities have been recommended to be included in hamstring injury-prevention programs [55, 56]. The role and importance of neuromuscular training in rehabilitation has previously been discussed. The focus of these exercises should be on maintaining postural control and power development. Examples of such exercises can include but are not limited to high knee marching, forward falling running drills, explosive starting drills, and quick support running drills [9]. Improvements in lower extremity control and movement discrimination were demonstrated after completion of a 6-week program including these exercises [55]. It was also demonstrated that hamstring injuries can be reduced by completing a program that emphasized varying trunk positions and movements during sport-specific drills, stretching while muscles are fatigued, and increasing the amount of anaerobic interval training drills. Athletes participated in a sport-specific drill that involved varying running speeds while in a forward flexed position. The authors reported that by adding this prevention program, hamstring injury occurrence was significantly reduced over a 2-year period [56].

Summary

Although hamstring strains are relatively common among athletes, the rehabilitation and recovery remain challenging due to frequent reoccurrences. These injuries can lead to reduced muscle length and suboptimal performance in elongated positions which if not addressed may lead to re-injury [48]. Due to the multifactorial nature of hamstring strains, a thorough evaluation of all local and adjacent strength, range of motion, and flexibility should be included in the examination. The specific mechanism of injury and location of the injury allow medical professionals to make a more accurate prognosis. Recent studies support the use of neuromuscular training as well as eccentric training as being important components of the rehabilitation program in order to return athletes to sport and reduce their risk of re-injury [9]. Recent literature demonstrates the effectiveness of prevention programs in reducing the risk of injury and the rate of re-injury in athletes [52, 54]. Future research should evaluate the effectiveness of current operative and non-operative rehabilitation programs, establish easy-to-administer and meaningful return-to-sport tests and criteria, and determine the most effective and efficient injury-prevention strategies.

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