Muscle injuries of the rectus femoris muscle. MR update

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Abstract
The tear of the anterior rectus femoris is the most frequent injury of the quadriceps muscle group, and one of the most common causes of lower limb muscle lesions (after the injury of the hamstring muscle group). As its anatomy is complex, and symptoms may be unclear, imaging and in particular, Magnetic Resonance Imaging (MRI) provides precise information on the type of tear, topography, extent, and severity. This article presents a detailed description of the anatomy of the RF and a selective study by MRI, with specific technical inputs to optimise this study method. The current concepts of tendinous, myoteninous, and the infrequent myofascial muscle-tendon tears are also addressed, providing key data that must be considered in MRI reports and which are of paramount importance for the orthopedist.

Keywords: Magnetic Resonance; Rectus femoris; Soft tissue injuries.

Introduction
Injury of the quadriceps muscle group is very common in the general population and even more common in athletes, generally due to hyperextension of the hip with knee flexion (in activities which involve kicking, running, martial arts, etc.). It is the most common cause of muscle tear in the lower limbs, second only to the injury of the hamstring muscle group. The quadriceps muscle group consists of four muscles: the rectus femoris (RF), vastus lateralis (VL), vastus medialis (VM) and vastus intermedius (VI). Of the four muscles that comprise this group, the RF is the only one that crosses two joints; therefore, in addition to being part of the group of primary hip flexors, the RF is also a knee extensor. Because of this feature, its fusiform shape, its tendency to an eccentric contraction and its high percentage of type II rapid contraction fibers, the RF is more frequently injured than the rest of the quadriceps vastus muscles.

Patients with RF injury present with various symptoms; therefore, imaging methods play an essential role in determining the type of tear, topography and severity. Ultrasound is a low-cost modality and permits examination of muscle fibers and soft tissue, but magnetic resonance imaging (MRI) has higher specificity for diagnosing the etiology, mainly in the subacute and chronic stages of the injury, when soft tissue edema is minor.

This article describes the anatomy and current concepts in MRI of rectus femoris tear, from its proximal insertion site to involvement of the quadriceps tendon.

Anatomic aspects of the rectus femoris
The RF is the only one of the four portions of the quadriceps that crosses two joints. While the VM, VL and VI extend from the femur to the tibia and are essential for knee extension, the RF extends from the hip bone to the tibia, and also acts as flexor of the coxofemoral joint.

The RF is a bipennate muscle; i.e., it is composed of fascicles that are arranged at an angle to the central tendon or oriented with the longitudinal axis of the muscle, giving greater muscle strength. The anatomy of the RF is complex but easily differentiated on MR imaging (figs. 1 and 2). Its proximal site of insertion is made up of two portions, a direct head (DH) and an indirect or reflected head (IH): the former arises from the anterior inferior iliac spine, while the latter arises from the superior acetabular ridge and the lateral aspect of the hip joint capsule. The DH acts mainly in the beginning of hip flexion, while the IH acts once the hip joint flexion has started. A few millimeters from their proximal insertion, both heads form a conjoined tendon; however, they are then located at...
different sites in the thigh. The DH lies in the anterior and slightly medial aspects; it has a short course with a proximal myotendinous junction in the thigh and its tendinous fibers course towards the anterior surface of the RC, blending with the proximal fascia\textsuperscript{1,14,15}. At this level, under normal conditions, it may be difficult to anatomically differentiate between the anterior fascia and the myotendinous junction, as there is a slight focal tendon thickening in continuity with the fascia (fig. 1c). On the other hand, the IH has a horizontal ovoid shape; it extends through the muscle belly, then it becomes thinner, reaching the inferior third of the thigh with a lineal shape with a sagittal major axis\textsuperscript{1,16-18}. The quadriceps tendon is a trilaminar structure formed by the coalescence of four tendons. The RF (superficial plane) and vastus intermedius (deep plane) insert on the superior border of the patella, while the VM and VL insert on the medial and lateral aspects, respectively, forming the patellar retinacula (intermediate plane). Then as the patellar tendon they reach the anterior tuberosity of the tibia\textsuperscript{19-21}.

**Magnetic Resonance Imaging**

Because of the large size of the RF in the thigh, complete visualization of this muscle may be difficult on MRI. For this reason, we suggest first obtaining coronal images with a wide field of view (FOV 400/420 mm) including both thighs, from the anterior-inferior iliac spine to both patellae in order to make a comparative assessment of their volume and determine the site to be studied. Then selective sequences may be obtained with higher resolution, focused on the region of interest. Our study protocol includes coronal and axial T2-weighted fat-suppressed images (repetition time [TR]/echo time [TE] 2500/90 ms), axial double echo T2-weighted images (TR/TE1

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**Figure 1.** Normal anatomy. Axial proton density (PD)-weighted images: (a) proximal insertion of the DH (black arrow) and (b) of the IH (white arrow); (c) proximal myotendinous junction of the IH (white arrow) and of the DH (black arrow) in the proximal third of the thigh; (d) myotendinous junction of the IH in the middle third of the thigh (white arrow).
2400 / 8 ms; TR/TE 2400/ 110 ms) and coronal T1-weighted images (TR/TE 500/ 18 ms).

Optionally, T2-weighted fat-suppressed images may also be obtained in a strict sagittal plane parallel to the thigh axis (patients with myofascial junction injury or myotendinous injury of the DH) and in the sagittal oblique plane paralleling the anterior-inferior iliac spine (when proximal tendinous injuries are suspected). The evaluation may be supplemented with T1-weighted fat-suppressed images to assess blood collections with greater imaging contrast, as they appear spontaneously hyperintense at the acute stage; gradient echo (GRE) sequences are helpful to identify sequellar lesions with hemosiderin deposits (blooming effect) appearing as markedly hypointense focal areas. Intravenous paramagnetic contrast administration is not usually necessary, although enhancement may be occasionally observed predominantly in the periphery of acute tears, associated with regionally hypervascularity.

**Tear of the rectus femoris and MRI findings**

Certain drugs (steroids, fluoroquinolone, among others) as well as a history of diabetes, gout, systemic lupus erythematosus, rheumatoid arthritis, kidney failure and obesity may all be predisposing factors for muscle tears. In addition, some cases of bilateral RF tear have been reported in these patients.

Muscle injuries most commonly occur in middle-aged male patients due to indirect muscle overload, as a result of dissipation of forces during muscle contraction. Injuries may be caused by a direct mechanism (contusion, laceration) or by an indirect mechanism (stretching of fibers beyond their elastic...
limit by a sudden and forceful contraction). As regards topography, these injuries are typically located in the tendon portion, myotendinous junction (most common site of tear) and/or myofascial junction. Generally, in acute injuries highly marked symptoms often occur immediately after the injury, but in acute injuries of the myotendinous and myofascial junction of the IH of the RF, symptoms may have an insidious onset. Furthermore, a tear may remain asymptomatic because of recruitment of all other quadriceps muscles, although in this case the patient will not have the same muscle strength he/she had before his/her injury. For this reason, MRI plays an essential role for determining the location, extent and severity of the RF injury and, consequently, for establishing a proper therapeutic management. A fibrillar involvement larger than 15% of the muscle area with a length greater than 13 cm and a location central to the muscle belly, has a poor prognosis and longer rehabilitation. An early diagnosis is essential to prevent muscle retraction and formation of scarring.

**Muscle contusion**

Contusion is common on the surface of the RF in the thigh. It is characterized by the presence of diffuse myofibrillar edema with no defined tear, with or without associated bruises and increased muscle volume compared with the contralateral side. In cases of RF injury from contusion, or in severe tears, hematomas are observed, which appear spontaneously hyperintense or hypointense on T1-weighted images, depending on the composition and the time of evolution. Hematoma results from intramuscular vein injury and it may be either intramuscular or intermuscular. The former is limited by the intact muscle fascia, which increases intramuscular pressure and consequently compresses bleeding vessels, limiting bleeding and size of hematoma. Instead, the intermuscular hematoma spreads into the interstitial and interfascial spaces due to rupture of the muscle fascia, without an increase in the pressure within the region; therefore the hematoma becomes larger in size. Chronic hematomas should be differentiated from tumor masses, as both have a heterogeneous appearance. The former may have mural nodules due to neovascularization with a fibrous capsule that appears hypointense in all sequences. Occasionally, the only way to differentiate them is by follow-up, observing a decrease in the size of hematomas. For this reason, radiologists should perform an accurate measurement of their size and determine the mass effect on adjacent structures, as well as their relationship with the sartorius muscle. If this muscle is compressed, recovery and drainage of metabolites in the area may be impaired.
Proximal tendon injury

This injury is classified as partial or total (fig. 4). As mentioned above, axial images and sagittal oblique images paralleling the anterior-inferior iliac spine are very useful for determining which tendon is affected (DH and/or IH of the RF), and in the case of complete tears, these images are helpful for an accurate measurement of the gap of the tear. These injuries may be associated with avulsion of the anterior-inferior iliac spine at the DH, as this tendon acts primarily in early hip flexion, which makes it more vulnerable. Avulsions typically occur in skeletally immature patients (avulsion of the apophysis of the anterior inferior iliac spine)\(^2,35,36\).

Repetitive microtrauma may result in chronic avulsion which must be differentiated from tumors because they present excess bone growth\(^2,37,38\).

Myotendinous junction injury

Myotendinous junction injury is the most common type of tear of the RF (especially for the IH), as this is a point of biomechanical weakness of the muscle. As regards the severity of myotendinous junction injuries, there are three categories\(^2\):

- **Grade I**: microscopic injury with no functional loss. The MRI shows edema and peritendinous interstitial hemorrhage with no focal area of tear. Edema extends into adjacent muscle fibers producing a “feathery” appearance (fig. 5). Less than 5% of myofibrils are affected\(^1,6\).

- **Grade II**: partial tear with partial loss of muscle strength and range of motion. The MRI shows partial tear of the myotendinous junction; the appearance of the tear will depend on the extent and age of the injury. In acute injuries, there is a fluid-filled partial defect and hemorrhage surrounding the myotendinous junction. In axial T2-weighted sequences the bull’s eye sign has been seen, characterized by a hypointense central tendon surrounded by an area of hyperintensity (hemorrhage and peritendinous fluid)\(^2,38\) (fig. 6).

- **Grade III**: complete tear with or without retraction with complete functional impairment\(^2\) (fig. 7).

The location of the myotendinous junction injury of the DH is anterior and proximal to the thigh. On MRI, this injury typically presents as edema and fluid between the proximal and anterior third of the RF and the muscle fascia. Because of its proximity to the anterior fascia, it may be difficult to distinguish a myotendinous junction injury from a tear of the myofascial junction. Some authors suggest that myotendinous junction injuries of the DH may be associated with some myofascial component\(^1\).

Anatomically, the myotendinous junction of the IH has a greater cephalocaudal extension than the DH and it is located at the center of the fibers of the RF muscle belly. Therefore, it is far easier to visualize an injury at this level on MRI. Such injuries are usually located between the proximal and middle thirds of the thigh; fluid and edema are irregularly seen, depending on the severity of the injury\(^1,2\).

Figure 6 Grade II tear of the myotendinous junction of the IH. Axial (a) and coronal (b) T2-weighted fat-suppressed images show peritendinous edema (solid arrow) and focal discontinuity of muscle fibers with fluid content (dashed arrow). Note the bull’s eye sign in the axial plane with central IH.

Figure 7 Axial T2-weighted fat-suppressed image showing the absence of the IH with complete discontinuity of the myotendinous junction and a heterogeneous area with intramuscular hematoma (arrow).
Myofascial junction injury

Myofascial junction injury is less common than the above reported injuries, and it usually leads to false negative results in ultrasound scans. Even if this injury may be located at any site of the muscle belly with or without facial disruption, it is usually located between the proximal and middle thirds of the thigh. On MRI, this injury presents as muscle fibers that lose their typical morphology and present signs of edema with partial involvement or complete tear of the adjacent fascia. Fluid collections dissect the plane between the fascia and the muscle belly (intact fascia) (fig. 8) and they may also spread into the intermuscular plane (fascial tear) (fig. 9). As noted earlier, it may be difficult to distinguish a myotendinous junction tear of the DH from a myofascial tear of proximal and anterior fibers, because of their proximity. On the contrary, a posterolateral myofascial tear can be easily distinguished from a myotendinous tear of the IH, as the former presents as edema and/or fluid collections distributed eccentrically to the muscle belly, while the latter is located around the IH at the center of the RF muscle.1,2

Distal tendon injury

As reported earlier, the quadriceps tendon typically has a trilaminar appearance (56% of cases), formed by the confluence of all four tendons in three layers (superficial layer: RF; intermediate layer: VM and VL, and deep layer: VI) For this reason, visualization of interdigitating fat among these tendons is normal. Injury at this level may be partial or total, and affect one or several tendons (fig. 10). This lesion is frequently located in the superficial layer, i.e., in the portion formed by the RF (fig. 11). Complete tears will require surgical therapy and findings will include retraction of the torn ends of the tendon, waviness of the patellar tendon and a decrease in patellar height.10, 20, 21 In general, patients with a history of past injury of the quadriceps or hamstrings have an increased risk for reinjury of the RF.1 For this reason, a single scan may show injuries at acute or chronic stages, and/or as exacerbation of an old injury.10, 21 Chronic tears often manifest as fatty replacement and myofibrillar atrophy, associated with hypointense linear tracts on T1- and T2-weighted images evidencing fibrosis and scar tissue around or adjacent to the tendon. Additionally, a blooming effect can be seen on GRE sequences, with a markedly hypointense signal from hemosiderin deposition (fig. 12). For educational purposes, two tables are included as a summary: table 1 describes anatomic aspects of the RF that are relevant for MRI and table 2 summarizes the issues that should be addressed in the radiologist’s report and which are relevant for the orthopedic therapy approach.

In conclusion, MR imaging of the RF muscle provides accurate data on the severity and extent of the injury, and it is also helpful to determine whether this injury is a de novo tear or an exacerbation of a chronic tear. A general assessment of the thigh (ideally an initial MRI comparing both thighs) followed by a few selective sequences with a higher resolution in the region of interest can provide accurate information about the location of the injury. Furthermore, MRI scans play an essential role for differential diagnosis in patients with uncertain symptoms, frequently associated with grade I myotendinous junction injury or myofascial junction tear that are difficult to visualize on ultrasound.
Figure 10 Complete tear of the distal tendon of the RF. Coronal T1-weighted image showing retraction of the torn end of the distal tendon (solid arrow) associated with waviness of the muscle belly (dashed arrow).

Figure 11 Sagittal T2-weighted fat-suppressed image in a patient with complete tear of the distal tendon of the RF (solid arrow) and intrasubstance injury of the torn end of the tendon. The dashed arrow shows the standard insertion of tendons of the VM and VL (intermediate plane) and VI (deep plane). The scan also shows suprapatellar fat pad edema (asterisk).

Figure 12. Patient with exacerbated chronic tear of the proximal myotendinous junction of the IH (short arrows) and of the posteroalteral myofascial junction of the RF (long arrows). (a) Axial T-weighted fat-suppressed image showing edema from tears in the acute stage. (b) Axial GRE sequence showing a hypointense signal from hemosiderin deposit, associated with a past history of sequellar tear.

Table 1: Anatomical and Imaging keys of the rectus femoris.

- The DH contributes to the most medial and anterior aspect of the muscle belly of the rectus femoris and the IH contributes to the posterolateral portion of the RF.
- Under normal conditions, the DH can be visualized on MRI at the level of the hip; instead, if there is edema or fluid, it can be visualized in its full length to the proximal third of the thigh.
- Sagittal oblique images paralleling the anterior-inferior iliac spine are helpful for visualization of proximal tendons (DH and IH) and of the gap of the tear.
- Gradient echo (GRE) sequences are helpful to detect hemosiderin deposits in scar injuries. In addition, T1-weighted sequences identify the presence of fatty replacement in these injuries.

DH: direct head; IH: indirect or reflected head.
Table 2: Magnetic Resonance Imaging report: what does the orthopedist expect?

- Determining the topography of the tear: tendinous (DH and/or IH), myotendinous and/or myofascial junction.
- Extent of the tear (approximate percent of fibers affected in a section area).
- In cases of complete tear, report measurement of the size of the gap and status of the torn ends of tendons,
- Description of the topography and measurement of fluid collections or hematomas (impact on the sartorius muscle?).
- Intact or affected muscle fascia.

DH: direct head; IH: indirect or reflected head.

Ethical responsibilities

Protection of human subjects and animals. The authors declare that no experiments were performed on humans or animals for this investigation.

Confidentiality of data. The authors declare that this article does not contain patient data.

Right to privacy and informed consent. The authors declare that this article does not contain patient data.

Conflicts of interest

The authors declare no conflicts of interest, except for Dr. Mariluis, who declares a possible conflict of interest as member of the Writing Committee of Revista Argentina de Radiología.

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