Muscle injuries in Sports: Correlation between anatomy and imaging study

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Muscle injuries in sports: Imaging study

Abstract. *A large segment of the population participates in sporting activities. Muscle injuries account for approximately one third of the injuries. The recreational and professional demands of modern society require an early and accurate diagnosis of these, for an adequate treatment and follow-up, given the economic and media implications, especially in elite athletes. Imaging plays a fundamental role in the evaluation of these lesions. It allows evaluation of location, extent, severity and estimate prognosis, as well as the follow-up to determine the return to sport.*
In this article, the microscopic and macroscopic muscle anatomy, the physiology, the types of lesions and their representation in images, both on ultrasound (US) and on magnetic resonance (MRI), are reviewed. Different classifications described in the literature are mentioned and a nomenclature and description are proposed, based mainly on the muscle anatomy, the location and the quantification of the lesion.
Key words: Muscle tear, Sports-related muscle injury, Classification of muscle tear.

Resumen. *Un gran segmento de la población participa en actividades deportivas. Las lesiones musculares corresponden a aproximadamente un tercio de las mismas. Las demandas recreacionales y profesionales de la sociedad moderna exigen un diagnóstico precoz y preciso, para un adecuado tratamiento y seguimiento, dadas las implicancias económicas y mediáticas, especialmente en deportistas de elite.*
La imagenología tiene un rol fundamental en la evaluación de estas lesiones. Permite evaluación localización, extensión, severidad y estimar pronóstico, así como también el seguimiento para determinar el retorno deportivo.
En este artículo se revisa la anatomía microscópica y macroscópica muscular, la fisiología, los tipos de lesiones y su representación en imágenes, tanto en ultrasonido (US), como en resonancia magnética (RM). Se mencionan distintas clasificaciones descritas en la literatura y se propone una nueva nomenclatura y descripción, basada principalmente en la anatomía muscular, la localización y cuantificación de las lesiones.
Palabras clave: Desgarro muscular, Lesión muscular deportiva, Clasificación desgarro muscular.

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I. Anatomical and physiological concepts

For the correct interpretation of the findings, both on ultrasound and MRI, it is essential to know the microscopic and macroscopic muscle anatomy.

The striated muscle as a whole, can be considered the largest organ of the body. It represents approximately 25 to 30% of body weight in women and 40 to 50% in men. It consists of two components: muscle fibers and stromal connective tissue.

The cell or muscle fiber is the basic structural element. It measures between 10 - 120 µm. Inside, there are sarcomeres where the actin and myosin filaments are found, responsible for the contraction and elongation of the muscles[2].

The individual muscle fibers are grouped into bundles called fascicles, which in turn are grouped together to form the muscles. They vary in length and transverse diameter depending on each muscle and tend to be similar in size within a given muscle.

The connective tissue provides the framework to maintain muscle shape in both relaxed and contracted states.

Each muscle fiber is surrounded by a delicate network of connective tissue, the endomysium, which contains small vessels, nerves and proteoglycan matrix for ionic and metabolic exchange.

Several muscle fibers form a fascicle that surrounds a thicker connective tissue, the perimysium that also provides vascularization, innervation and matrix.

Several fascicles form a muscle surrounded by an outer layer of connective tissue, the epimysium[3] (Figure 1).

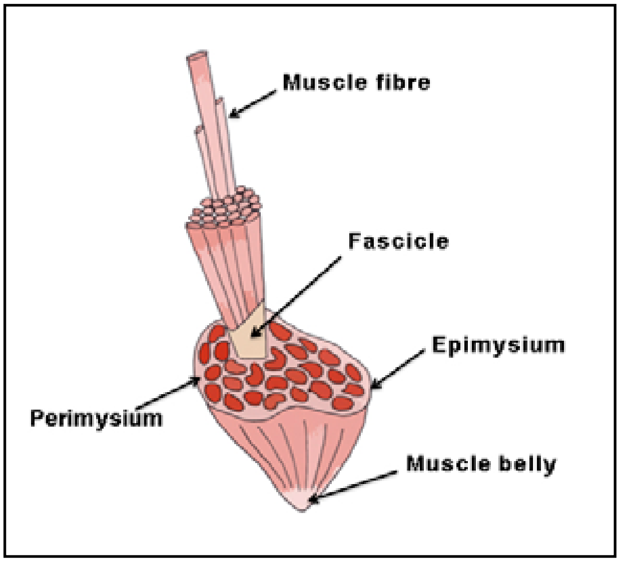


Figure 1. *Drawing of the microscopic anatomy and the connective tissue of the striated muscle*

The muscle fibers are inserted into different connective tissue components, including the aponeurosis, the intramuscular aponeurotic septa (central tendons) or directly into the tendon. The internal disposition varies according to the orientation of the fascicles, which determines the shape and function of the muscle:

• When the fascicles are oriented parallel to the line of traction, a high degree of shortening and high velocity of movement occurs, however, the force is low. Examples of these are the ribbon-like muscles such as the sartorius or the rectus abdominis.

• when the fascicles are oriented obliquely in relation to the line of traction, there is a larger insertion surface, which biomechanically generates greater force with a lower range of motion4 (Figure 2).

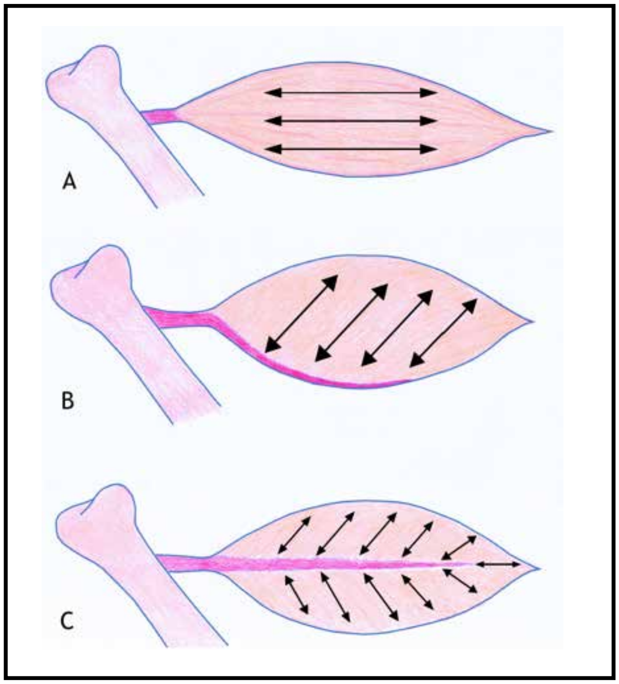


Figure 2. *Diagram of muscle strength in relation to the fascicular orientation (green lines): A. fusiform muscle, B. unipennate muscle, C. bipennate muscle.*

The oblique orientation of the fascicles is typical of the pennate muscles (also called a penniform muscle, from Latin penna: pen and forma: form). There are several types of pennate muscles (Figure 3).

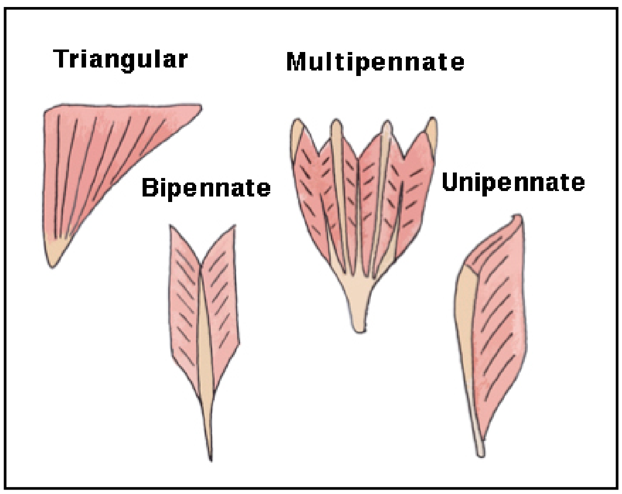


Figure 3. *Drawing of pennate muscles (modified from 5).*

In the bipennate muscles the fascicles converge in a single central tendon, whereas the multipennates have more than one tendon. The fascicles can also adopt a spiral arrangement in muscles that curve or have a spiral path such as the supinator or the pectoralis major (Figure 4).

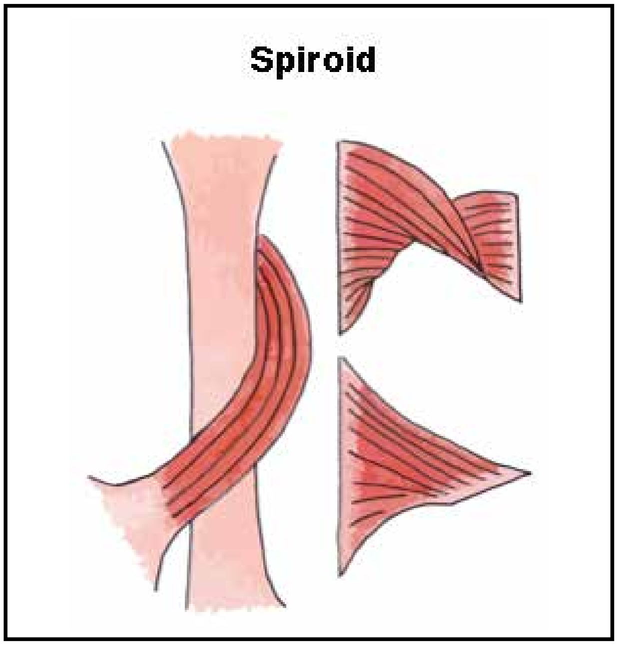


Figure 4. *Drawing of spiroid muscles.*

On the other hand, the muscles can have a single belly or can be formed by the union of two or three heads such as the biceps brachii or triceps, which join in a distal tendon[5].

From the histological point of view there are two types of muscle fibers:

- *Type I or slow contraction (slow-twitch):* they have a smaller diameter, more mitochondria, myoglobin and capillaries per fiber, more suitable for repetitive contraction, with greater resistance to fatigue.
- *Type II or rapid contraction (fast-twitch):* larger, with fewer blood vessels and myoglobin, more suitable for fast phasic forces, better adapted for intense activity of short duration and greater tension[6].

The active tension produced by a muscle is proportional to the type of fibers it contains, so that muscles with a high proportion of type II fibers are capable of generating greater force.

Low intensity exercises selectively involve type I fibers, while type II fibers are recruited when the intensity of the exercise increases.

Sprinters, for example, have a predominance of type II fibers, while in marathon runners type I predominate. It is not clear if this predominance is genetically determined or if it is a response to training.

Muscle tears are more frequent in muscles with predominance of type II fibers[7,8].

Each muscle is made up of a mixture of both types of fibers. In some, type II predominates (example: medial calf) and in others type I (example: soleus).

During muscle contraction the force is transmitted to the skeleton from the tendon, generating three types of effect[3,4] (Figure 5):

A. Isometric contraction: the muscle contracts, but does not change its length.
B. Isotonic contraction: the muscle contracts and shortens.
C. Eccentric contraction: the muscle contracts and at the same time lengthens.

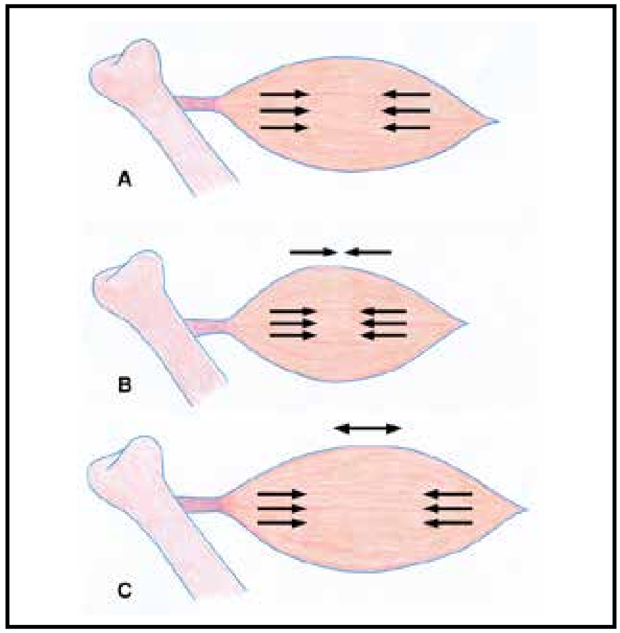


Figure 5. *Diagram of muscle contraction types: A) Isometric contraction. B) Isotonic contraction. C) Eccentric contraction.*

A tear occurs when the tension exceeds the strength of the weakest structural element. It has been experimentally demonstrated that muscle stretched to failure, always ruptures near the distal muscle-tendon junction[9].

This anatomical introduction is relevant, because muscle tears occur predominantly in biarticular muscles (that cross more than one joint), of eccentric action, with a high proportion of type II fibers, in anatomical or functional transition zones, corresponding to the insertion of the fascicles in the fascias, aponeuroses or tendons, whether central or distal, since these sites generate the highest concentration of intrinsic forces, which is why they are the points of greatest biomechanical weakness[10].

Movement is the result of the muscle contraction, where a muscle group performs the predominant function. Other muscles, called synergists, act in the same direction of movement, supporting the main group. Antagonists are those which oppose the action[3]. For the correct contraction of one muscle another is required to relax, allowing the expected normal movement. If the main muscle contracts disproportionately in relation to its antagonist, it will not support the traction and will rupture during the contraction. Thus, an optimal training that corrects and improves muscle coordination, which includes strength and resistance work, is essential to reduce the incidence of these injuries.

II. Methods for studying muscle injuries

X-Ray Study

Simple radiography (X-ray) has a limited role because the musculature does not have a good representation on it. It may be useful to detect calcifications or if ossifying myositis is suspected in the evolution of a muscle lesion.

Computed tomography is not indicated for the evaluation of tears. It can be useful to differentiate if calcifications are muscular or are in contact with the bone cortex.

US and MRI are the examinations of choice[11-14]; the decision as to which one to use depends on the experience of the radiologist and the availability of appropriate equipment.

In our environment, US is the best exploration technique in the vast majority of cases.

MRI study

MRI is reproducible, with multiplanar capacity, high tissue contrast, high sensitivity, lower specificity, with the advantage of exploring large areas in a single image. It is more expensive and less available than US.

In very subtle or very extensive lesions, MRI may perform better.

MRI studies in the face of suspected muscle injuries should include enhanced sequences in T1, T2, Proton Density with fat saturation (PD FS) and STIR. Axial, coronal and sagittal planes should be carried out. We recommend the study covering the entire extension of the affected muscle group.

US Study

US is a real-time examination, which allows the diagnosis to be made immediately, it's dynamic and eventually comparative. It is less expensive than MRI, with greater availability in our environment and can serve as support for interventional procedures, such as aspiration of the hematoma or injection of PRP (platelet-rich plasma). The drawbacks of US are related to the small visual field, the need for an expert operator and that it is a non-reproducible examination.

The choice of transducer depends on the size and depth of the muscle or muscle group to be examined. Choosing between 7-12 MHz is appropriate for most cases, however, the definition may be insufficient for small muscles. Also, in very voluminous patients or those with hypertrophy of the musculature, it may be necessary to use transducers of less frequency.

The examination should be done on the short and long axis of each muscle.

The echo-structure of a muscle consists of a hypoechoic fundus that reflects muscle fascicles and delimited linear hyperechoic bands that represent fibro-fatty septa, the perimysium. The intramuscular aponeuroses and tendons appear as hyperechoic bands, which are better visualized on the short axis of the muscle4,5. The distribution between these components explain the proportion between muscle fascicles and connective tissue. US can recognize the internal architecture of the muscles and hence the importance of knowing the anatomy of the muscle studied.

In the transverse plane, short axis, the ultrasound appearance of the muscle has been described as a "starry night" with the visualization of hyperechoic dots (perimysium) within a hypoechoic background (muscle fascicles) (Figures 6a, b).

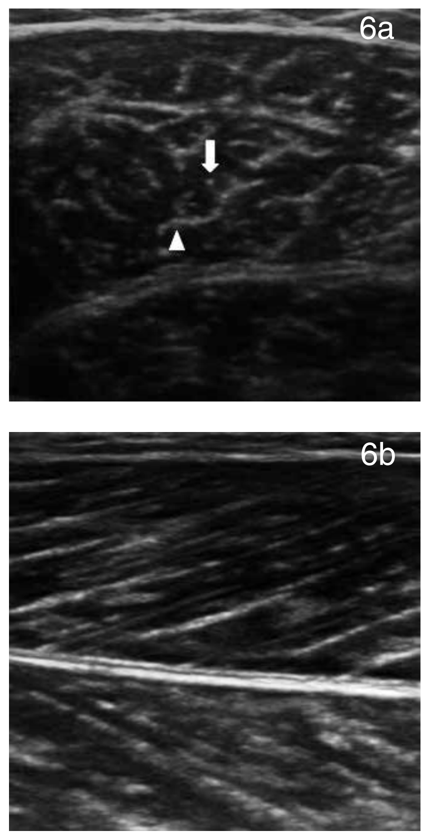


Figure 6. *US of the normal muscle echo-structure: Perimysium (arrow). Central tendon (arrow head). a) cross section. b) longitudinal slice.*

The angle between the ultrasound beam and the muscle is fundamental. An angle that deviates from the perpendicular causes the muscle to look hypo or hyperechogenic as an artifact (Anisotropy)[4]

The ultrasound semiology of muscle injuries is limited, which makes the clinical correlation indispensable for a correct interpretation of the findings.

In practically all the injuries we will see one or more of the following signs:

- Diffuse increase or decrease in echogenicity: depending on the moment of exploration in relation to the traumatic event, it can explain microscopic fibrillar lesion, edema, recent bleeding or inflammatory process.
- Distortion of the architecture or fascicular pattern: corresponds to the distortion or loss of the pennate appearance.
- Continuity solution: it explains macroscopic disruption of fascicles. It is an avulsion and retraction of muscle fibers in relation to the tendon or aponeuroses where it is inserted, whether central intramuscular, peripheral or distal.
- Fluid collection: which corresponds to the hematoma.

III. Types of sports-related muscle injuries

According to their mechanism they have been classified in:

A. Intrinsic or indirect: not caused by an external force.
B. Extrinsic or direct: the cause is an external force.

A. Intrinsic or indirect injuries

I) Tears

They correspond to a spectrum of lesions ranging from the minimal microscopic fibrillar lesion, in which a macroscopic defect is not identified, to the complete rupture of a muscle belly.

They occur because of excessive or simultaneous stretching to a sudden eccentric contraction. There is structural damage of muscle tissue, breakage of fibers and/or fascicles. The most frequent mechanism is a sudden elongation at the time of eccentric contraction, which is common in sports involving acceleration-deceleration or sudden changes in direction.

Over the years different classifications of muscle injuries have been described in the literature, both for US and MRI, most using degrees from 0 to 4, depending on the author. None have been universally accepted. Following are mentioned the ones most used[10,15] (Table 1):

In 2012, a meeting of international experts in sports medicine was held to develop practical and scientific definitions of muscle injuries, as well as a new classification system. It is known as the Munich Consensus[10], (Level of evidence V. Expert opinion), whose suggestion is summarized in Table 2.

Table 1. Different classifications of muscle injuries.

Author	Year	Method
O 'Donoghue	1962	-
Ryan	1969	Described for quadriceps
Takebayashi	1995	US
Petrons	2002	US
Stoller	2007	MRI
Munich Consensus	2012	US-MRI
Pollock	2015	MRI

Table 2. Summary of classification for acute muscle injuries according to the Munich Consensus.

A. Indirect	Functional muscle disorder	Type 1: Disorder related to excessive force	Type 1A: Fatigue Induced Type 1B: DOMS
		Type 2: Neuromuscular disorder	Type 2A: Related to the spinal cord Type 2B: Related to the muscle
	Structural muscle injury	Type 3: Partial muscle rupture	Type 3A: Minor partial tear Type 3B: Moderate partial tear
		Type 4: Total or subtotal rupture	Total or subtotal rupture (> 50%) Tendinous avulsion
B. Direct	Contusion Laceration		

This classification includes neuromuscular disorders (type 2), which move away from the interest of this article.

In our experience, no classification is fully able to answer the information necessary for the clinical management of sports-related muscle injuries. In our opinion, an exhaustive description of the alteration and its location is more useful than a classification in degrees, as will be discussed further on.

Following are reviewed the imaging aspects of the indirect muscle injuries type 1, 3, 4 and of direct lesions (in Munich classification).

The vast majority of patients seen in radiological practice, whether amateur or professional athletes, correspond to type 3 injuries.

To interpret the imaging aspect of the lesions it is necessary to remember that the muscle fibers are microscopic, so that a "fibrillar" lesion is not represented as a defect or gap in the muscle tissue. The fibers are organized into fascicles measuring between 2 and 5 mm, which can be viewed using imaging.

So, we will call that which involves a smaller diameter than a fascicle, a minor partial tear (3A or "fibrillary") and that in which more than one fascicle is involved, a moderate partial tear (3B or "fascicular").

US and MRI do not always accurately determine the size of the defect and may overestimate the damage due to edema on US and the signal increase on MRI[11].

Sometimes we find patients with positive clinical examination, in which the imaging findings are negative. In these cases, the patient has suffered a "contracture", terminology that the Munich consensus does not recommend using. It would correspond to a functional disorder related to excessive force induced by fatigue or type 1A injury in the Munich consensus. There is no structural muscle damage. There is pain and painful palpation of a large area, including a muscle group.

"Fibrillary" tear (or 3A minor partial in the Munich consensus)

Corresponds to the minimum fibrillary lesion. It produces slight discomfort at the time of the injury. There is pain to the passive elongation of the muscle and focal pain on palpation.

There is not a defect in the muscle. It produces distortion of the architecture, edema and/or hemorrhage in the area of the lesion, in areas of anatomical transition.

It must be taken into account that, in small lesions, the ultrasound manifestations may take hours to appear, so that US study should not be performed immediately after the traumatic event, since it may be negative. In cases of positive focal clinical and negative US study, we recommend reevaluating after 24 hours.

From an ultrasound point of view, there may be a focal increase or decrease in echogenicity, associated or not with distortion of the architecture and the normal fascicular pattern (Figure 7 a,b,c).

On MRI the fibrillar lesion is observed as signal increase in fluid-sensitive sequences, without fluid collection, without macroscopic defect (Figure 8 a,b).

It is not always easy to quantify the size of the lesion. Our recommendation for both methods is to measure the dimensions of the alteration on the short and long axis. These lesions usually heal ad integrum, without fibrous scar formation.

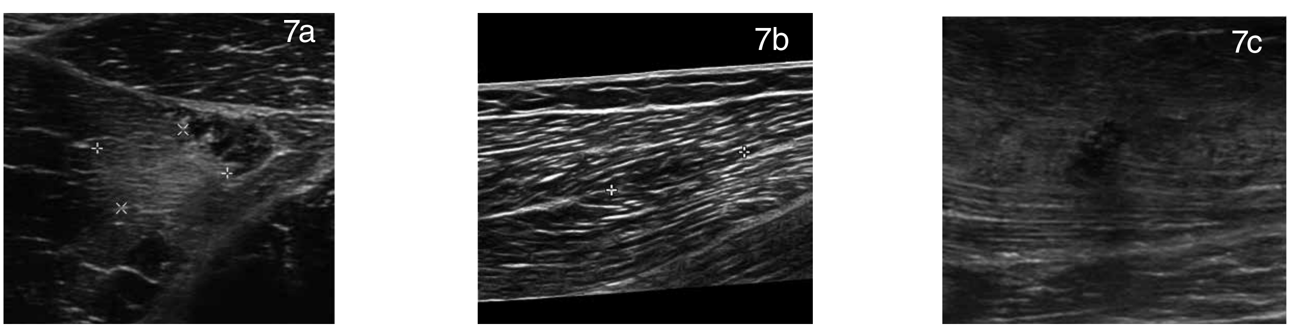


Figure 7. *Fibrillary lesion on US: a) Focal increase of echogenicity with measurement on the short axis (cross). b) Reduced focal echogenicity on long axis (cross). c) Distortion of the muscle architecture.*

Figure 8. *Fibrillary lesion on MRI. a) Axial PD FS with measurement on short axis (dashed line). b) Coronal PD FS with measurement on long axis.*

Partial "fascicular" tear (3B moderate in the Munich consensus)

This corresponds to the partial lesion with involvement of muscle fascicles that are visible macroscopically. It produces intense pain at the time of injury, local pain on palpation and passive elongation. The athlete must stop the activity. Local contractility is lost. Fascicles and adjacent connective tissue (endomysium and perimysium) are affected, which helps to differentiate them from the fibrillar lesion.

Fiber disruption, probable shrinkage and hematoma of these will be seen.

Considering that the blood flow is increased when the muscle is active, these lesions quickly produce bleeding. This hemorrhage has different ways of presenting, depending on the integrity of the fascia. If it is undamaged, the bruise is confined to the muscle. If the fascia is broken, the hematoma accumulates in the intermuscular or subcutaneous space. This is the case in which patients present with ecchymosis.

The hematoma is the hallmark of the muscle rupture and its appearance on US depends on the location of the injury and the time elapsed. In acute or recent hemorrhage, it is usually echogenic (Figure 9a). Within a few hours it behaves as a hypoechogenic and homogeneous collection (Figure 9b), an appearance that remains for a variable time depending, among other things, on its size. In more chronic stage, the elements of the blood, cells, serum, fibrin etc., can be separated and give as a result a fluid-fluid level. After a few days, the collection becomes uniform, anechoic, which is called a "serosal" stage hematoma (Figure 9c).

To estimate the size of the lesion, which can sometimes be variable and difficult, the following is suggested:

- If the tear occurs at the central myotendinous or myoaponeurotic junction, we recommend linear measurement of the hematoma on the short and long axis of the muscle (Figure 10a and 10b). Their dimensions, in general, coincide with the magnitude of the damage.
- If the tear occurs at the junction of the fibers to the fascia (peripheral myofascial), without rupture of the fascia, we recommend curve measurement on the short axis at the periphery of the muscle (Figure 11a) and measurement on the long axis, also at the periphery (Figure 11b). Usually the dimensions of the hematoma coincide with the extent of the lesion.
- If the tear is located peripheral myofascial with rupture of the muscle fascia, the hematoma is not contained within the muscle and accumulates in the intermuscular space. In this situation, it is more difficult to estimate the amount of damage, since the size of the hematoma does not necessarily coincide with the extent of the lesion. We recommend the estimation of the tear on the short and long axis, and the measurement of the intermuscular hematoma separately (Figure 12).

On US and MRI, the same criteria for the quantification of the lesions are used. The disadvantage of MRI is that sometimes it can be difficult to differentiate the edema from the hematoma, since sometimes both can appear similar (Figure 13).

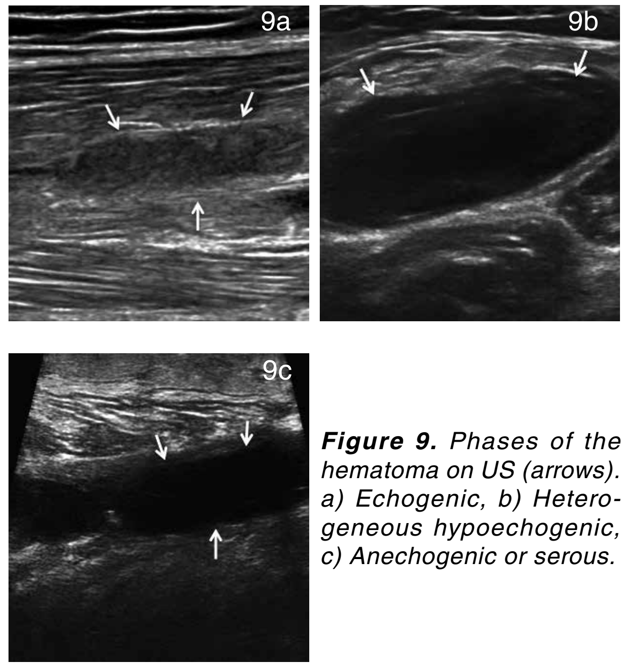


Figure 9. *Phases of the hematoma on US (arrows). a) Echogenic, b) Heterogeneous hypoechogenic, c) Anechogenic or serous.*

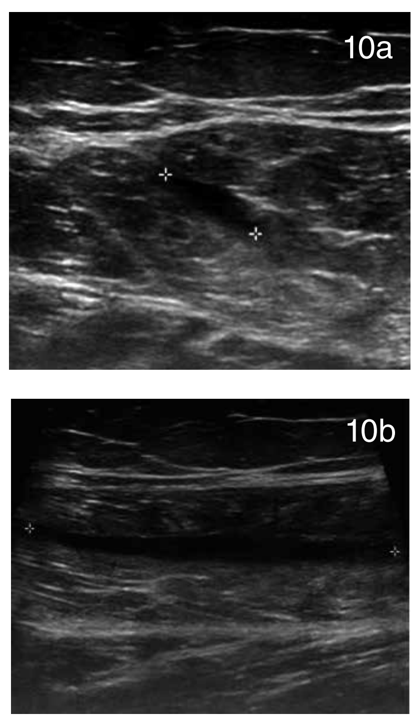


Figure 10. *Myotendinous or central myoaponeurotic fascicular tear with measurement (cross) on US. a) Short axis, b) Long axis.*

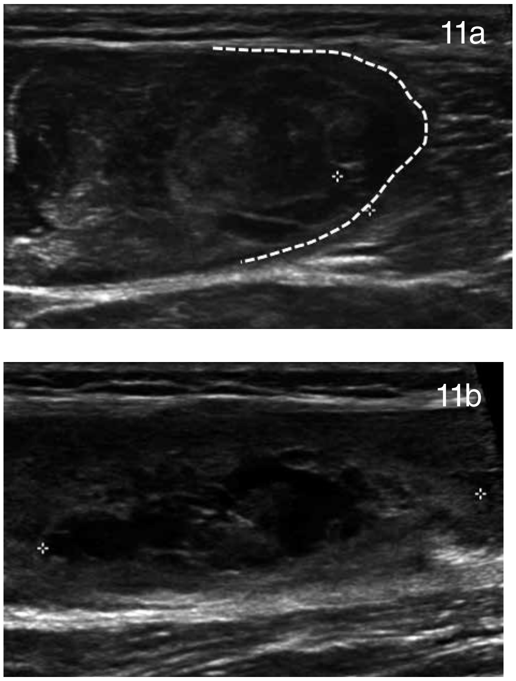
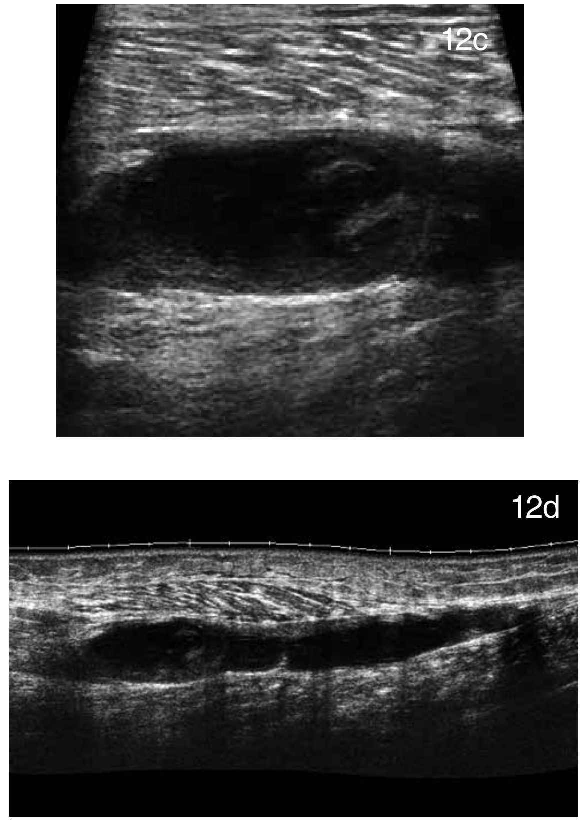


Figure 11. *Fascicular tear in myofascial location, without rupture of the fascia on US. a) Short axis, distortion and disruption of fibers, partial defects and retraction, with curve measurement of the circumferential extension affecting the muscle (dotted line). b) Long axis, longitudinal measurement (cross) of muscle defect with hematoma.*



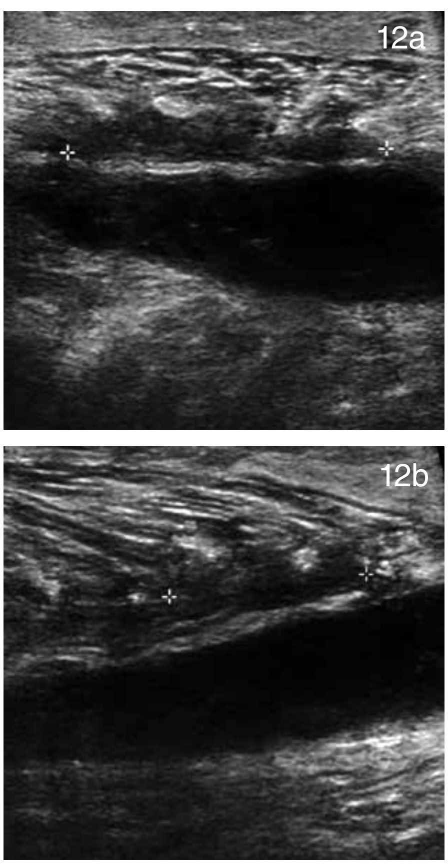


Figure 12. *Fascicular tear in the myofascial location, with rupture of the fascia and intermuscular hematoma on US. a) Short axis of the tear with measurement (cross), b) Long axis of the tear with measurement (cross), c) Short axis of the hematoma, d) Long axis of the hematoma in extended vision.*

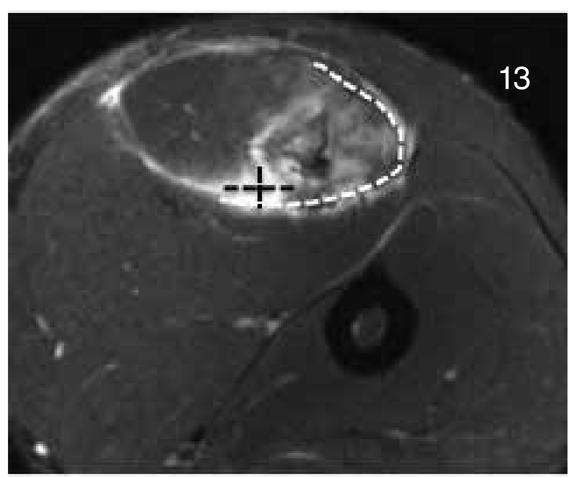


Figure 13. *Fascicular tear in myofascial location, with edema but without fascial rupture on axial PD FS MRI. Curved measurement of the circumferential extension of affected muscle (white lines). Measurement of muscle defect with hematoma (black lines).*

Total tear - Subtotal (or type 4 in Munich consensus)

Complete rupture of a muscle belly is rare. Subtotal tears, which involve more than 50% and avulsions are more frequent.

Clinical experience has shown that the healing time of subtotal and total ruptures is similar.

Avulsions are included in this category, since biomechanically they correspond to a complete rupture of the insertion origin. The most frequent sites are the proximal femoral rectus insertion, hamstring, long adductor and distal insertion of the semitendinosus.

The patient presents with severe pain and loss of function, with a palpable defect and ecchymosis.

On US, the examination can be difficult due to the limited visual field. There is a continuity solution that involves all the thickness of the muscle and fluid collection interposed between the ends of the rupture.

On MRI it is relatively easier to assess the size of the defect and the hematoma.

II) DOMS (Type 1B in Munich consensus)

Acronym for Delayed Onset Muscle Soreness[16], this was described at the beginning of the century and its initial definition has not changed significantly. Its etiopathogenesis has not been clarified. It is estimated that virtually every adult person has once experienced late onset muscle pain.

It occurs in beginner athletes or athletes who perform eccentric activities. The symptoms consist of the appearance of muscle pain hours after strenuous or unaccustomed exercise, which lasts 5 to 7 days and which is self-limiting. The peak is 2 or 3 days after the exercise. There is characteristic acute inflammatory pain, due to the local release of inflammatory mediators.

On US, an increase in the volume of the affected muscle is observed, associated with a diffuse increase in echogenicity due to edema (Figure 14), which can also be seen on MRI.

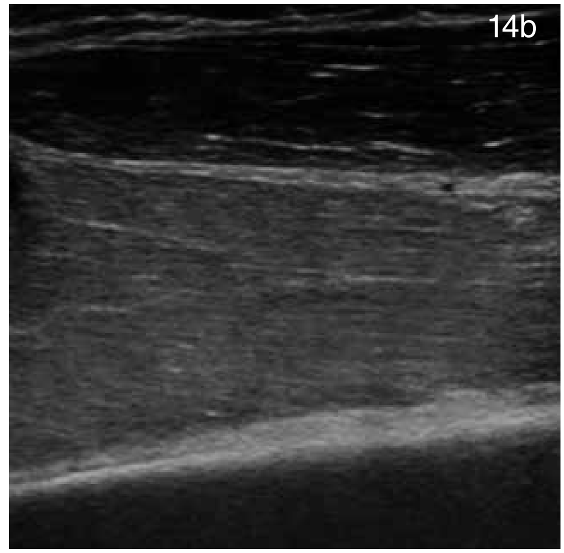


__Figure 14.__ DOMS on US. Muscle edema with marked increase in echogenicity and volume of the affected muscle, without alteration of the muscle architecture. a) Short axis, b) Long axis.

B. Extrinsic or Direct injuries

Contusion - Laceration (Type B in Munich consensus)

The muscle contusion corresponds to a compression of the muscle by direct trauma. It results from the collision of the muscle mass against a hard surface and the bone; these are frequent in contact sports such as rugby, soccer (football), etc. Its severity depends on the contact force and the contraction situation of the muscle at the time of the trauma. It usually affects muscles in a deep location, adjacent to the bone plane, such as the vastus intermedius (intermediate vast) in the thigh. It causes bleeding that precociously produces a diffuse hyperechogenic appearance of the area, transforming over time into a mixed hypoechoic area with progressive better delimitation. The normal fibrillar pattern is lost. It can affect more than one muscle. On both US and MRI there is edema, hemorrhage, continuity solution, architectural distortion and fluid collection - hematoma.

The laceration results from penetrating injuries and is seen in sports such as water skiing, motorcycling, etc. It is accompanied by a continuity solution in the skin and more frequently affects superficial muscles.

Therefore, from our experience and considering the classifications described in literature we propose the following imagenological description of sports-related muscle injuries, based on the muscle anatomy, the location and the type of lesion (Table 3).

Table 3. Proposal for description of muscle injuries in sports.

Type of injury	Location	Fascia	Definition	Hematoma	Ultrasound	MRI
Fibrillar tear	Central or peripheral	It does not affect the fascia.	Affects muscle fibers (microscopic). There is no intramuscular "defect".	There is no detectable fluid collection Edema and/or focal hemorrhage.	Focal increase or decrease in echogenicity. Pennate architecture distortion.	Focal increase of signal in fluid sensitive sequences.
Fascicular tear	Central (myotendineal or central aponeurotic muscle).	It does not affect the fascia.	Affects fascicles (macroscopic) There is intramuscular "defect" in central myoaponeurotic junctions.	Intramuscular hematoma.	Intramuscular defect, associated with distortion of the architecture, with fluid/hematoma collection.	Central intramuscular myoaponeurotic fluid collection. Muscle edema.
	Peripheral (peripheral myofascial).	No rupture of the fascia.	Affects fascicles (macroscopic) There is "defect" in peripheral myofascial junctions without fascial rupture.	Peripheral intramuscular hematoma inside the fascia.	Intramuscular defect with fluid collection in the periphery of the muscle, subfascial.	Subfascial fluid collection. Muscle edema.
		With rupture of the fascia.	Affects fascicles (macroscopic) There is "defect" in peripheral myofascial junctions with fascial rupture.	Intermuscular and/or subcutaneous hematoma (ecchymosis).	Peripheral myofascial intramuscular defect. Intermuscular intermuscular. fluid collection.	Peripheral fluid collection communicated with intermuscular and/or subcutaneous space. Muscle edema.
Subtotal tear	Large muscle groups such as hamstrings or quadriceps.	Usually there is a rupture of the fascia.	Rupture of more than 50% of the muscle belly on the short axis.	Large bruise interposed in the muscle defect.	Large fluid collection interposed in the "gap" or muscle belly defect.	Fluid collection, defect or rupture of fibers with retraction of ends. Muscle edema.
Total tear	Large muscle groups such as hamstrings or quadriceps.	There is always a rupture of the fascia.	Complete rupture of the muscle belly. Includes a subtotal tear. Complete avulsion of the insertion (without rupture of the fascia).	Large bruise interposed in the muscle defect and intermuscular and/or subcutaneous plane.	Intramuscular defect with retraction of ends and collection interposed in the area of rupture.	Fluid collection. Defect that affects the entire muscle. belly. Retraction of ends.
Laceration Contusion	Generally lower extremity. Thigh most frequently. Generally more than one muscle affected.	Contusion: usually does not affect the fascia. Laceration: There is always a rupture in the fascia.	From focus of edema/hemorrhage to subtotal or total rupture.	Depends on the extent of the injury. From focal edema to large intramuscular fluid collection and eventually interfascial-subcutaneous	From focal edema to a large intramuscular fluid collection. Increased echogenicity. Architecture distortion.	Edema. Intramuscular defect. Intramuscular fluid collection. Eventually retraction of cabos.

IV. Evolution of injuries.

- Part of the role of imaging is to monitor the evolution of tears and detect eventual complications[6,19] in our environment, especially with US.
- In the fibrillar tears, we look for the resolution of the edema or hemorrhage by comparing the dimensions of the affected area. These injuries usually repair ad integrum.
- In fascicular tears, the hematoma changes progressively. The cavity is “filled” with hypoechoic tissue from the periphery to the center.
- The information relevant to the clinician is the presence of residual fluid hematoma and edema of muscle fibers, in later stages the appearance of a scar.
- In total tears, subtotals and tendon avulsions we also evaluate the regression of the hematoma, which usually takes longer than in the previous lesions, these lesions being the ones with the slowest recovery and the worst prognosis.

The repair physiopathology

Muscle injuries are usually self-limiting. To make a correct interpretation of the findings in images, it is important that in addition to the anatomy, we know the physiopathology of these lesions. In an acute injury there is fiber destruction followed by necrosis, local inflammation and hematoma formation. Then the necrotic area is invaded by small blood vessels, mononuclear cells, macrophages and T lymphocytes that infiltrate locally. These secrete cytokines and growth factors. The lesions that affect the soft tissues of the musculoskeletal system are resolved by a mechanism mainly of repair, unlike bone lesions that heal by regeneration.

The healing model of muscle injuries includes 3 well-differentiated phases, lasting approximately 3 weeks[17,18].

1. Destruction phase: In the first days there is degeneration and active inflammation. In this period the rupture of the muscle tissue and the necrosis of the myofibrils takes place with the formation of a hematoma between the broken fibers. In addition, an inflammatory cell reaction occurs.
2. Repair phase: Where the necrotic tissue reabsorption occurs, the regeneration of myofibrils and the production of an area of connective tissue and new capillaries. Regeneration usually begins between 7 and 10 days. The peak of regeneration is two weeks and decreases in the third and fourth.
3. Remodeling phase: The new newly formed myofibrils are matured, the reorganization of the tissue that will allow to recover the contractile capacity of the new muscle. The formation of a scar (fibrosis) begins between the second and third week, and the scar increases in size over time.

The 3 phases overlap in time (Figure 15).

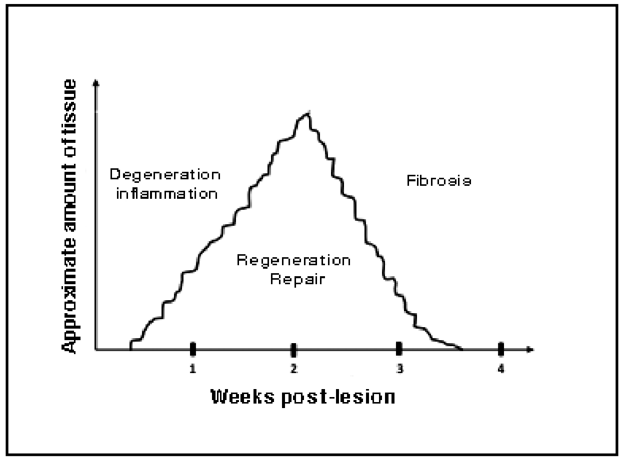


Figure 15. *Graph of muscle repair.*

Complications

Muscle scar

All macroscopic muscle injuries heal with fibrosis to a greater or lesser degree. When the lesions are not treated properly, the result is a fibrous-retractable scar that constitutes a complication, determining new anatomical transition zones that predispose to re-tears[19].

When the treatment is early and adequate, a greater degree of regeneration can be achieved versus scarring and the result will be less fibrosis.

Both on US and MRI, a stellate, retractable image can be observed, associated with a decrease in volume and muscle atrophy in the fibers adjacent to the scar.

Muscle hernia

It constitutes a possible complication of tears that have affected the fascia. It is defined as the protrusion of a part of the muscle through a fascial defect. Most are asymptomatic, although they can sometimes cause pain or edema in the area of the hernia. The best imaging tool is US at rest and dynamic, where it is possible to demonstrate the size of the defect of the fascia and the portion of muscle through it[20].

Others

Other complications that may occur are chronic compartmental syndrome and calcifications-myositis ossificans[21-23].

Conclusion

Muscle injuries in sport are very frequent. The role of imaging is fundamental in the diagnosis and follow-up. US and MRI are the examinations of choice, the decision of which to use should consider the experience of the radiologist and the availability of appropriate equipment.

The radiologist must know the individual anatomy of each muscle and the clinical antecedents for the adequate interpretation of the imaging findings.

There are multiple classifications of sports-related muscle injuries, the vast majority in degrees, based mainly on MRI.

In this article we propose a nomenclature and description, based mainly on the muscle anatomy, the location and the type of the lesion, useful for both US and MRI. With this we hope to standardize diagnostic criteria and improve the management of these injuries.

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