



Magnetic resonance classification proposal for medial gastrocnemius muscle injuries

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Abstract: Calf muscle injuries are common among athletes and occupational populations, with highly variable recovery times that are challenging to be predicted at the initial clinical evaluation. Specifically, in distal gastrocnemius muscle injuries, an ultrasound-based severity classification has shown to be useful for estimating the recovery time. According to the location of lesions and the recognition of some US signs, four types of injuries of the distal gastrocnemius muscle were described. Since magnetic resonance imaging (MRI) has proven to be useful in diagnosing and prognosticating muscle injuries by assessing the extent of affected connective tissue, a specific MRI protocol involving T1-weighted and fluid-sensitive static and dynamic acquisitions has been developed aimed to characterize the four types of injuries. We here describe the characteristics of this new MRI protocol and the interpretation of images, which will be useful to improve the recognition of acute and delayed distal gastrocnemius muscle injuries. The proposed classification includes: myoaponeurotic muscle injury without aponeurotic discontinuities (type 1), myoaponeurotic muscle injury with aponeurotic discontinuities (type 2), isolated free aponeurosis discontinuity (type 3), and a mixed myoaponeurotic-aponeurotic injury pattern (type 4). A comprehensive understanding of the MRI features associated with each injury type, in conjunction with multidisciplinary team collaboration, is essential for optimizing the athlete's recovery and return to play.

Keywords: Calf muscles; medial gastrocnemius injuries; magnetic resonance imaging (MRI); ultrasound (US)

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Introduction

Calf muscle injuries are frequent among both professional and amateur athletes and occupational groups (1,2). Recovery times are highly variable, lasting from a few months to years, depending on the site and severity of the injury (1,3-5). Therefore, an accurate diagnosis at the time of injury is a crucial step for the outcome of injured athletes.

Sonography and magnetic resonance imaging (MRI) are essential in the approach of muscular sports injuries that would otherwise be treated clinically. To this purpose, image-guided severity classifications of muscle injuries have been developed and become increasingly important in the overall assessment of lesions (6-8). However, general classifications of muscle injuries do not completely take into account the complexity of injuries of the medial head of the gastrocnemius especially because of its histological features and anatomic variability (9). The distal part of the distal gastrocnemius consists of a complex anatomy given the organization of the connective tissue (10,11). At this level, the anterior and posterior aponeurosis of the medial gastrocnemius, in conjunction with the soleus aponeurosis (SA), converge to form the “free gastrocnemius aponeurosis” (FGA), which ultimately integrates with the Achilles tendon (10,11).

Based on the understanding of these particular characteristics, Pedret *et al.* (12) proposed an ultrasound (US) classification to determine the type of injury according to its location and characteristics. Depending on their location, the lesions can be myoaponeurotic, aponeurotic or mixed, demonstrating different prognoses regarding the time to return to play or to work activities (12).

In the last decade, MRI has proven to be very useful in the diagnosis and evolution of muscle injuries given its high ability to discriminate connective tissue (13-15). Sergot *et al.* (16) proposed a classification that includes the muscle groups of the triceps surae with prognostic correlation according to the degree of connective tissue involvement, without considering the specific location of the injury based on the characteristics of each muscular belly.

Hence, considering the widespread acceptance and clinical utility of the recent US classification specifically targeting the distal portion of the medial gastrocnemius (12), we aimed to develop an MRI protocol facilitating the US translation of injury types to MRI modality. This clinical practice educational review endeavor seeks to enhance the understanding and application of precise diagnostic

methodologies for calf muscle injuries, particularly focusing on their localization and characteristics within the mentioned anatomical context.

Normal anatomy and US-MRI correlation

The distal anatomy of the triceps surae exhibits numerous distinctive features that largely determine the occurrence of diverse injury patterns within the myoconnective complex. Understanding the distribution of normal myoconnective tissue is crucial for a comprehensive understanding of injuries (17-20). Both the medial and lateral heads of the gastrocnemius converge to form a singular broad aponeurosis, known as the anterior gastrocnemius aponeurosis (GA), located deeply across both muscle bellies. Generally, the GA has an area free of muscle fibers (FGA) just proximal to its junction with the SA. Distally, the FGA converge with the posterior SA to create the Achilles tendon (10,11).

The aponeuroses appear as echogenic linear structures surrounding these muscular bellies in US examination, whereas in MRI, they present markedly hypointense signals in T1 and fluid-sensitive sequences (13). Given the intermediate signal and echogenicity of the muscle fibers, the interface of the myoconnective junction is easily visualized with both techniques (12,13). However, the pattern of muscle fiber pennation, typically parallel in this location, is clearly visible through US but is not evaluable by MRI under normal conditions.

Finally, the biomechanical characteristics of the musculature at this level should be considered. Because of the presence of connective and fibroadipose tissue in the intermuscular space between the posterior aponeurosis of the soleus and the anterior aponeurosis of the gastrocnemius, there is synchronization in the movement of these muscle bellies during dorsal-flexion foot maneuver.

MR indications

MRI allows identification of the affected histoarchitecture and the magnitude of a muscle injury (13). MRI is generally recommended for deep muscle injuries that are difficult to evaluate by US and are suspected that will require a prolonged recovery time (13,21,22). Despite the superficial nature of the medial gastrocnemius and the extended and variable recovery time periods of this muscle injuries, the

Table 1 Recommended MRI protocol

Parameters	MRI characteristics							
	Axial fat-suppressed TSE intermediate-weighted image		Axial TSE T1-weighted image		Sagittal fat-suppressed TSE intermediate-weighted image		Sagittal TRUFI-cine T2-weighted image*	
	1.5 T	3 T	1.5 T	3 T	1.5 T	3 T	1.5 T	3 T
Echo time (ms)	37	34	9.6	9.8	39	32	1.79	3.74
Slices (number)	84	80	84	80	32	25	1 (20 acquisitions)	1 (20 acquisitions)
Section thickness (mm)	3	3	3	3	3	3	10	10
Interslice distance (mm)	0.2	0.2	0.2	0.2	0.2	0.2	2.0	2.0
Field-of-view (cm)	20×20	20×20	20×20	20×20	18×18	18×18	20×20	20×20
Repetition time (ms)	3,850	8,770	758	1,900	3,520	3,000	4.3	7.47
Flip angle (degrees)	110	138	110	127	180	134	56	30
Acquisition matrix	256×320	256×320	302×336	256×320	285×320	269×384	290×320	290×320
Bandwidth (Hertz/pixel)	180	180	156	221	135	220	504	300
Acceleration factor (R)	2	2	2	2	2	2	2	2
Scan time (min:s)	3:08	9:58	3:12	9:13	2:22	3:08	35 s	58 s

*, dynamic acquisition (foot dorsi-flexion); slices were acquired sequentially. MRI, magnetic resonance imaging; TSE, turbo spin-echo; TRUFI, true fast imaging with steady-state free precession; ms, milliseconds; mm, millimeters; cm, centimeters.

ability of MRI findings to assess the time to return to play and the risk of reinjury (14) has contributed significantly to the growing popularity of this imaging technique in the professional sports world due to the specificity for studying the connective tissue. Likewise, MRI has allowed the identification of milestones in the healing process following a muscle injury (15), enabling the translation of those histological features described by Järvinen *et al.* (23–25). Nevertheless, determining the clinical necessity of a diagnostic MRI should be established case-by-case (21). The primary limitations of MRI include its cost, higher length of examination compared to US, and occasional feeling of claustrophobia reported by some patients. In terms of monitoring, US allows early detection of the onset of delayed hematomas and complications frequently reported as deep venous thrombosis.

MRI protocol

Utilizing a 3 Tesla MRI or an optimized 1.5 Tesla system enables specialists to precisely define muscle injuries, acquiring images in two planes, including static and dynamic acquisitions. The examination is specifically

focused around the region marked with a skin vitamin marker, based on clinical findings. The patient is prepared by placing an MRI sand bag under the leg at the level of the distal portion of the Achilles tendon. The flex coil is positioned on the leg (in supine position) strongly attached to maintain the extremity fixed preventing translational motion but allowing foot dorsiflexion. It is recommended to use a multipurpose surface coil for MRI to achieve higher resolution images. Our recommended protocol consisting of 3 sequences: two fat-suppressed intermediate-weighted [echo time (TE) range, 40–65 ms] sequences (axial and sagittal planes), and a T1-weighted sequence in the axial plane. The intermediate-weighted fluid sensitive sequences provide excellent contrast and spatial resolution of the connective tissue (13). Tailoring protocols is advised to ensure thin sections (e.g., less than 3 mm), appropriately small field of view (FOV) (13), and multiplanar acquisitions (axial, and sagittal). Then, we perform a dynamic examination with true fast imaging with steady-state free precession (TRUFI) cine imaging, looking for the asynchronous motion of the gastrocnemius and soleus muscles during ankle dorsiflexion and plantarflexion maneuvers. *Table 1* shows the recommended parameters.

Table 2 Translation to MRI of the ‘ultrasound classification of medial gastrocnemius injuries’

Types	Location of damage	Imaging findings	
		US signs	MRI signs
1	Muscular myoaponeurotic injury	Morphologic and echostructural alteration of muscle fascicles and the interposed fibro-adipose septa	Area of feathery edema is observed in the fibers anchored to the aponeurosis in fluid-sensitive sequences
2A	Gastrocnemius aponeurotic injury (<50%)	Morphologic and echostructural alteration of the aponeurosis continuity, as well as evidence of morphologic and echostructural alteration of muscle fascicles. Small hypo-anechoic collection (hematoma). Synchronous motion of the gastrocnemius and soleus muscles	Increased signal area at the myoaponeurotic junction, along with irregularity in the fibrillar pattern of the anchorage and a clear discontinuity in the aponeurosis at that level. Small liquid-signal accumulation (hematoma). Synchronous motion of the gastrocnemius and soleus muscles
2B	Gastrocnemius aponeurosis injury (>50%)	Morphologic and echostructural alteration of the aponeurosis continuity, as well as evidence of morphologic and echostructural alteration of muscle fascicles. Large hypo-anechoic accumulation (hematoma). Usually, asynchronous motion of the gastrocnemius and soleus muscles	Increased signal area at the myoaponeurotic junction, along with irregularity in the fibrillar pattern of the anchorage and a clear discontinuity in the aponeurosis at that level. Large liquid-signal accumulation (hematoma). Usually, asynchronous motion of the gastrocnemius and soleus muscles
3	FGA injury	Morphologic and echostructural alteration of the FGA. Synchronous motion of the gastrocnemius and soleus muscles	Exclusively a FGA discontinuity, and a small amount of fluid tends to accumulate superficially, although significant hematomas are not present. Synchronous motion of the gastrocnemius and soleus muscles
4	Mixed injury	Combination of US findings of 2B and 3 types	Combination of MRI findings of 2B and 3 types

MRI, magnetic resonance imaging; US, ultrasound; FGA, free gastrocnemius aponeurosis.

MRI interpretation

MRI fluid sensitive sequences allow the detection of edematous changes around the myoaponeurotic junctions, ensuring an accurate connective tissue assessment, as well as the delineating intramuscular or intermuscular fluid collections or hematomas (13,23,26,27). Areas of hyperintense signal on MRI may reveal disruption of the fibrillar pattern or discontinuities within the aponeuroses, indicating varying degrees of severity (13). Muscle overload is suggested when these areas of hyperintensity in fluid-sensitive sequences are not associate with loss of muscular architecture (13).

T1-weighted sequences are useful in the assessment of subacute hemorrhage or hematoma, in the detection of atrophy and fatty infiltration, and the identification of scar tissue in chronic injuries that may present as chemical shift artifacts in the T2-weighted or fluid-sensitive sequences (13,23).

Another benefit of MRI is its capacity for dynamic study allowing confirmation of the synchronicity of muscle movement, an aspect easily achieved with US as well (12). In dynamic examination using TRUFI cine imaging, it is essential to consider reference points from

both the gastrocnemius and soleus muscles to observe synchronization.

Lastly, in cases of injuries assessed for the first time after 7 days of evolution, image interpretation should encompass the evaluation of scar tissue alterations relative to the injury’s temporal progression, along with assessing the presence or absence of an intermuscular hematoma (15). This is another potential value of the MRI classification here described.

Proposed MRI classification

Hereafter are delineated the MRI findings corresponding to the various types of injury severity according to the US classification proposed by Pedret *et al.* (12). Using MRI, we can also identify 4 types of injuries based on the recognition of images from fluid-sensitive sequences, such as: disruption of fibers in areas of muscular hyperintensity, discontinuities in the internal GA, presence and extension of discontinuities in the free aponeurosis, extension of hematomas, and the presence of muscular asynchrony during dynamic acquisition (*Table 2*).

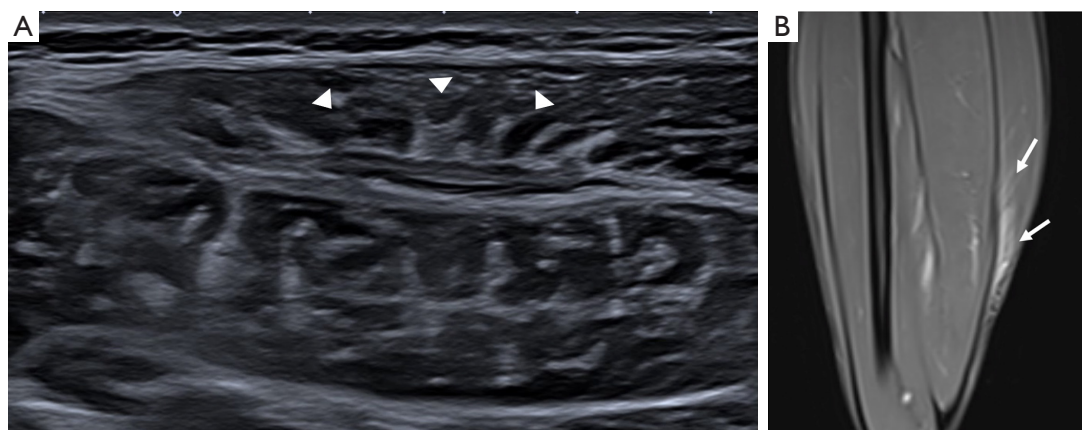
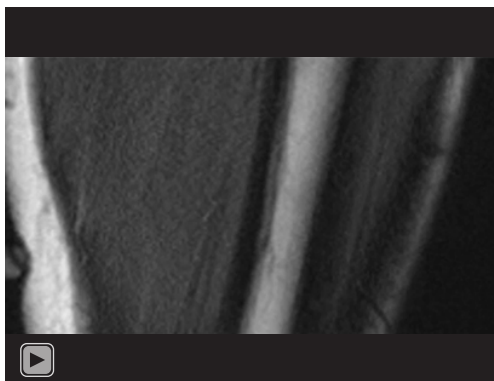


Figure 1 A 30-year-old futsal male player suffered from an acute stabbing pain felt at the medial aspect of the right calf during the match. At 72 hours a muscular myoaponeurotic injury (type 1) was diagnosed. Axial axis US image (A) of a type 1 injury shows the perimysium retracted with distortion of muscle fibers (arrowheads) and an intact aponeurosis. Sagittal fat-suppressed TSE intermediate-weighted image (B) of the same type of injury shows a thickening of the aponeurosis without gaps and feathery edema of the anchored muscle fibers (arrows). There is no hematomas. See *Video 1* showing synchronous motion of the gastrocnemius and soleus muscles. US, ultrasound; TSE, turbo spin-echo.



Video 1 Synchronous motion of the gastrocnemius and soleus muscles in a type 1 lesion.

Type 1: muscular myoaponeurotic injury

In this type of injury, an area of feathery edema is observed in the fibers anchored to the aponeurosis in fluid-sensitive sequences, without any discontinuities (*Figure 1*). However, the aponeurosis might appear slightly thickened with minimal loss of its normal signal on MRI. Similar to US, MRI displays gastrocnemius-soleus synchrony during dynamic maneuvers.

Type 2: gastrocnemius aponeurotic injury

In fluid-sensitive sequences, this type of injury presents an increased signal area at the myoaponeurotic junction, along with irregularities in the fibrillar pattern of the anchorage and a clear discontinuity in the aponeurosis at that level (*Figures 2,3*). Aponeurosis damage can be continuous, but more commonly by MRI, a ‘tandem’ pattern is observed as multiple focal discontinuities in the affected area. It is further classified into type 2A or 2B based on whether the transversal affected area of the aponeurosis is less than 50% or equal to or greater than 50%, respectively (12). Additionally, the presence of intermuscular hematomas is a characteristic feature (12). The asynchronous motion of the gastrocnemius and soleus muscles is mostly seen in subtype 2B.

Type 3: free GA injury

In this type of injury, there is exclusively an aponeurosis discontinuity and a small amount of fluid tends to accumulate superficially, although significant hematomas are not present (*Figure 4*). In these cases, MRI has a remarkable capability to determine the extent of connective tissue involvement, distinguishing a complete from a partial

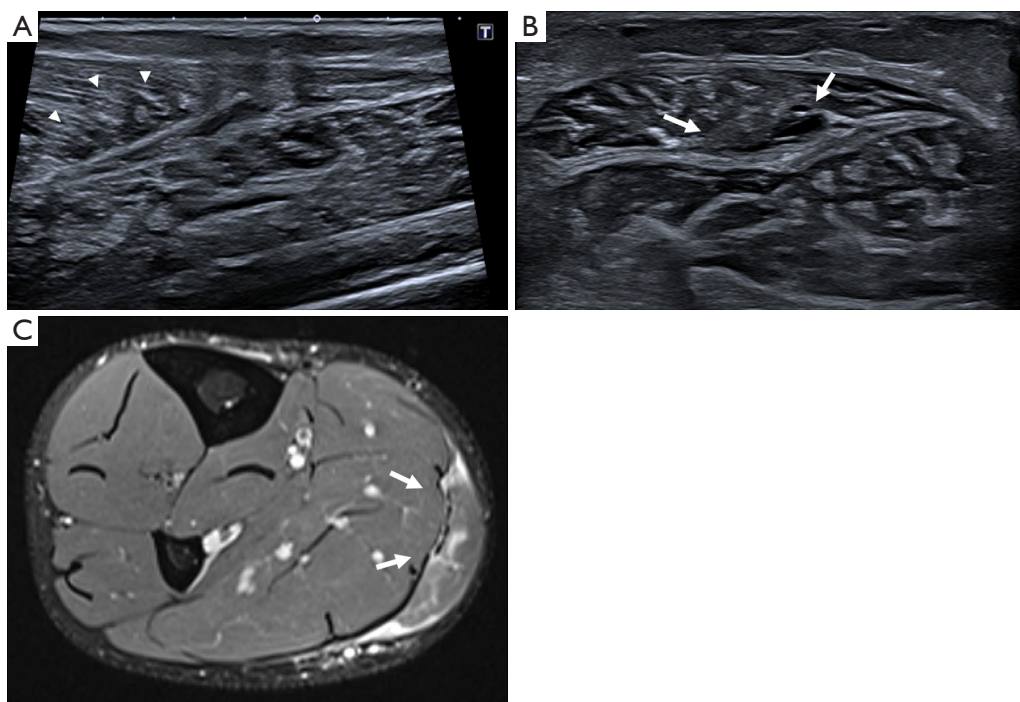
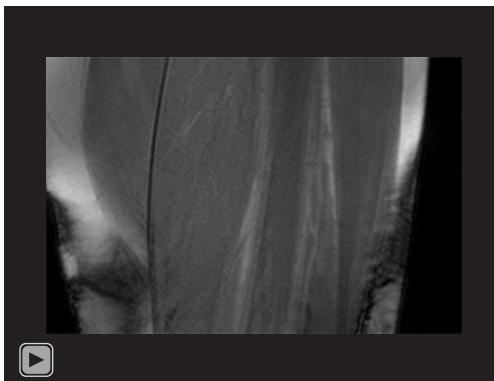


Figure 2 A 40-year-old woman, with a gastrocnemius aponeurotic injury (type 2A) at 48 hours, after suffering an acute pain of the calf during a tennis match. Long and axial axis US images (A,B) show the perimysium and muscle fascicles are retracted (arrowheads) secondary to an aponeurotic rupture affecting less than 50% of total muscle width (arrows) and a mild hematic intermuscular suffusion. Axial fat-suppressed TSE intermediate-weighted image (C) of the same type of injury shows an aponeurotic rupture affecting 50% of total muscle width (arrows) and feathery edema of the muscle fibers. There is no significant hematomas. See *Video 2* showing synchronous motion of the gastrocnemius and soleus muscles. US, ultrasound; TSE, turbo spin-echo.



Video 2 Synchronous motion of the gastrocnemius and soleus muscles in a type 2A lesion.

thickness tear. In cases with extensive involvement, a slight retraction of the muscular belly may be observed. However, MRI displays gastrocnemius-soleus synchrony during dynamic maneuvers. In these cases, the slight signal changes

in the muscle fibers at the myoconnective junction of the calf should not be interpreted as structural damage but rather as an overload.

Type 4: mixed injury

This injury involves over 50% impairment of the GA at the upper myoconnective junction (like type 2B lesions), with a disruption of the free GA (as type 3 lesions) (12). Discontinuities in the connective tissue are visible in fluid-sensitive sequences, along with extensive intermuscular hematomas leaking onto the posterior muscle surface (*Figure 5*). The asynchronous motion of the gastrocnemius and soleus muscles is a characteristic finding.

Special considerations

Among the differences between US and MRI findings, it is important to highlight the high sensitivity of the MRI

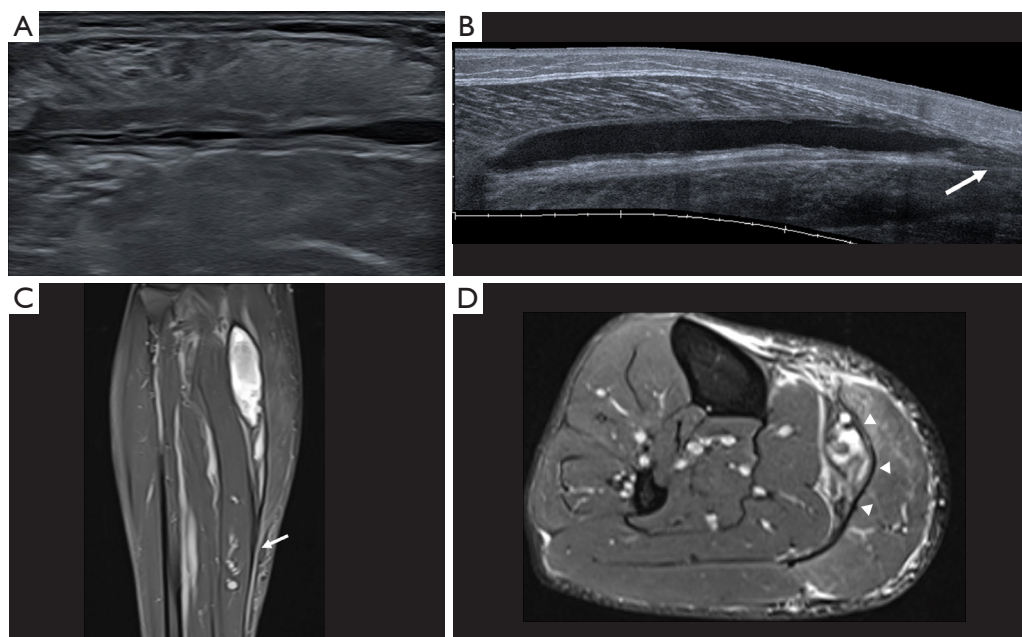
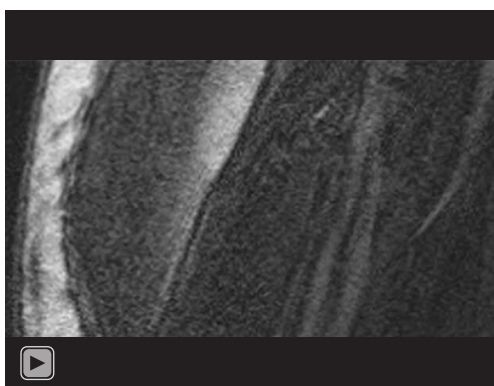


Figure 3 A 43-year-old man present a gastrocnemius aponeurotic injury (type 2B) at 5th day by US with a follow-up MRI at 3 weeks. He reported an acute injury while playing paddle and had to stop playing. Axial (A) and long (B) axis US images show the perimysium and muscle fascicles are retracted secondary to an aponeurotic rupture affecting more than 50% of total muscle width and a severe intermuscular hematoma. Free aponeurosis thick but without disruption (arrow). Sagittal/axial fat-suppressed TSE intermediate-weighted images (C,D) show the presence of reparative scar tissue along the anterior aponeurosis of the medial gastrocnemius muscle (arrowheads) with integrity of the free aponeurosis (arrow). See *Video 3* showing asynchronous motion of the gastrocnemius and soleus muscles. US, ultrasound; MRI, magnetic resonance imaging; TSE, turbo spin-echo.



Video 3 Asynchronous motion of the gastrocnemius and soleus muscles in a type 2B lesion.

technique in detecting tissue signal alterations in fluid-sensitive sequences (13). This sensitivity is particularly useful in type 1 lesions, where signal alteration is more pronounced than structural changes. Notably, the sensitivity

of MRI surpasses that of US. However, it is crucial to recognize that, in many cases, these signal alterations result from overload rather than tissue rupture. This underscores the importance of observing the edema pattern and its association with fibrillar pattern disruption or aponeurosis discontinuity.

In certain cases, muscle fiber edema due to overload may be observed in MRI studies without a clear clinical injury correlation. Similarly, when there is suspicion of muscle injury, pure type 3 lesions identified by US might exhibit signs of muscular overload at the myoconnective junction in MRI, without actual tissue damage at that level. This potential discrepancy may induce confusion. However, US is not free from these discrepancies in type 3 lesions; irregularities of the myoaponeurotic junction can be seen that do not correspond to a rupture but rather to retraction or overload secondary to the injury to the free aponeurosis. Nevertheless, in our experience, MRI has demonstrated a remarkable sensitivity in detecting small-

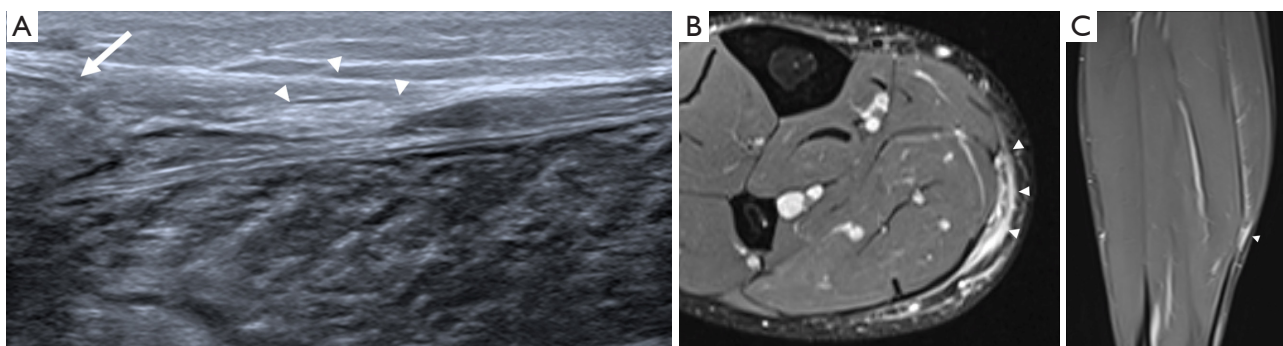
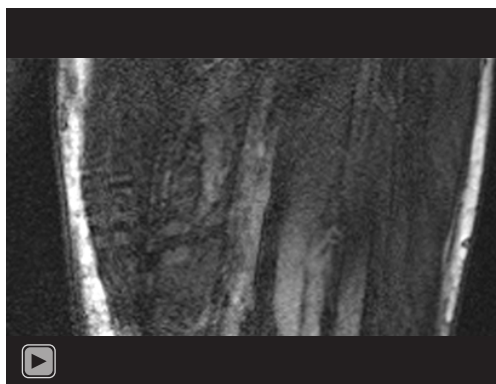


Figure 4 A 22-year-old male soccer player presents with severe pain during the match and a free gastrocnemius aponeurosis injury at 36 hours was diagnosed. Long axis US image (A) shows an altered echostructure with disruption (arrowheads). The distal fragment of the disruption shows a fusiform and thick shape. The muscle echostructure of the medial head of the gastrocnemius is minimally altered (arrow). Axial (B) and sagittal fat-suppressed TSE intermediate-weighted images (C) show a clear isolated gap in the free aponeurosis (arrowheads). There is no remarkable hematoma. See *Video 4* showing synchronous motion of the gastrocnemius and soleus muscles. US, ultrasound; TSE, turbo spin-echo.



Video 4 Synchronous motion of the gastrocnemius and soleus muscles in a type 3 lesion.

sized discontinuities in injuries with few symptoms or low clinical suspicion, which were uncertain in US assessments.

On the other hand, the detection of free aponeurosis and the extent of involvement were more effectively assessed by MRI. This was facilitated by the quantification of thickness through axial acquisitions in fluid-sensitive sequences.

However, despite the valuable insights that dynamic MRI studies can offer, interpreting them might be challenging in instances where the technician lacks familiarity. Nevertheless, this maneuver has proven to be exceedingly

easy to execute and interpret.

Recent studies on muscle tissue repair enable us to diagnose delayed muscle injuries (occurring more than 7 days after the initial trauma) by utilizing the milestones of the healing process (15). This empowers us to effectively manage injuries regardless of the timing of the patient's initial presentation, as long as we correlate it clinically with their medical history.

Conclusions

Both US and MRI are valuable techniques for the examination of distal injuries in the medial gastrocnemius. In this review, we have detailed and illustrated, through medical images, the correlation between US and MRI findings concerning various degrees of muscle involvement. In our clinical practice, we have successfully integrated the recently proposed US classification, complemented by the insights provided by MRI. It is essential to acknowledge the effectiveness of MRI in identifying patterns and the extent of connective tissue damage, particularly aponeurosis, while recognizing the US usefulness in visualizing gastrocnemius-soleus synchrony during foot dorsiflexion. The synergistic use of both modalities enhances our ability to comprehensively assess and manage distal injuries in the medial gastrocnemius.

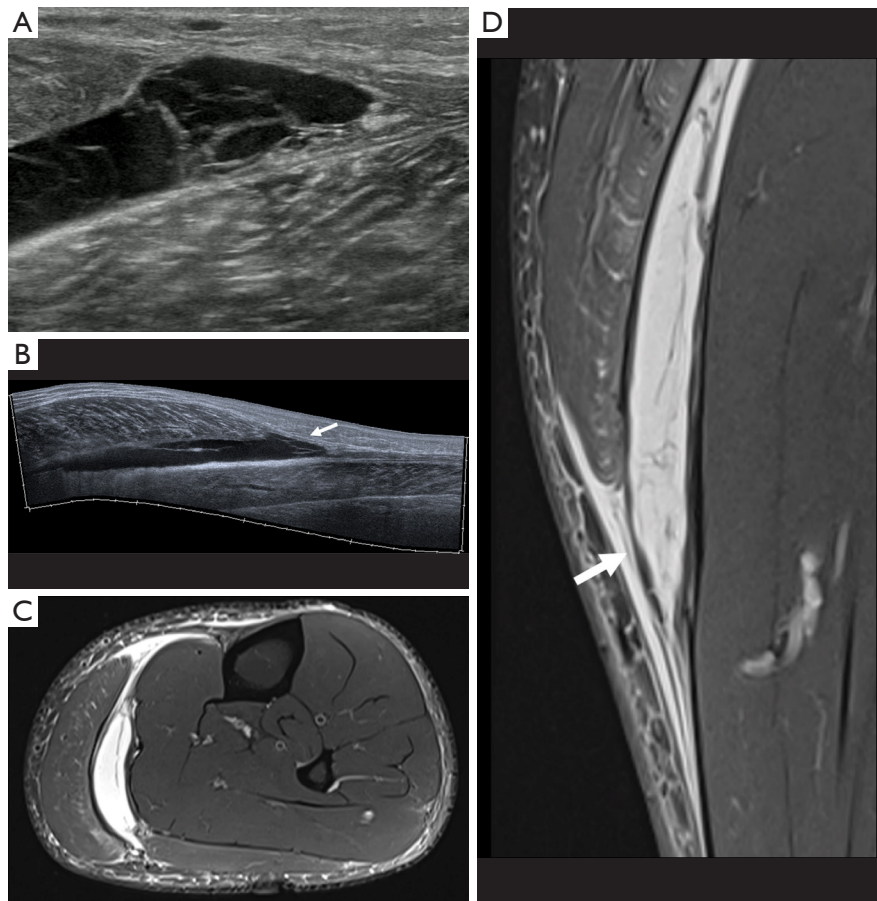
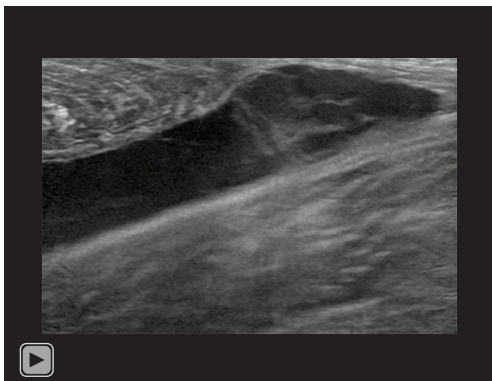
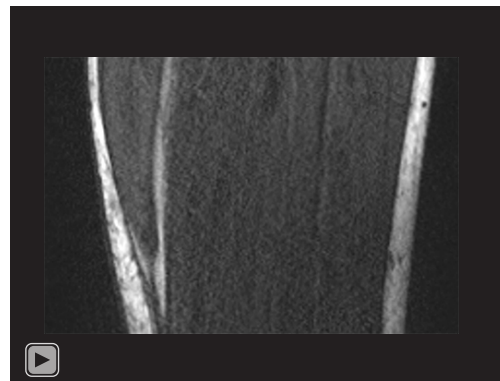


Figure 5 A 40-year-old male presents with severe pain during a paddle match that prevented him from continuing to play. A mixed injury (type 4) at 24 hours was diagnosed. Long axis US images (A,B), and sagittal/axial fat-suppressed TSE intermediate-weighted images (C,D) show a mixed injury where the perimysium and muscle fascicles are retracted secondary to an extensive aponeurotic rupture affecting the free aponeurosis (arrows) and severe intermuscular hematoma. See *Video 5* (US) and *Video 6* (MRI) showing asynchronous motion of the gastrocnemius and soleus muscles. US, ultrasound; TSE, turbo spin-echo; MRI, magnetic resonance imaging.



Video 5 Asynchronous motion of the gastrocnemius and soleus muscles by US in a type 4 lesion. US, ultrasound.



Video 6 Asynchronous motion of the gastrocnemius and soleus muscles by MRI in a type 4 lesion. MRI, magnetic resonance imaging.

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. All clinical procedures described in this study were performed in accordance with the ethical standards of the institutional and/or national research committee(s) and with the Helsinki Declaration (as revised in 2013). Written informed consent was obtained from the patients for the publication of this article, the accompanying images and videos.

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