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EDITORIAL

Anatomical Variability of the Soleus Muscle: A Key Factor for the Prognosis of Injuries?

Carles Pedret[1] · Ferran Rupérez[2,3,4] · Sandra Mechó[5] · Ramon Balius[2] · Gil Rodas[3,6]

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1 Challenges in Predicting the Prognosis of Soleus Muscle Injuries

Calf muscles are among the most commonly injured muscles in athletes [1] (especially in amateurs). To precisely predict the prognosis of the injuries and the time of return to play (RTP), the anatomical location of calf muscles and the involvement of connective tissue have been studied through different imaging techniques.

Having an accurate and early diagnosis is very important for the treatment of muscle injuries. In the calf, ultrasound (US) is the most widely used imaging method to detect lesions of the medial gastrocnemius, and even of the plantaris, with excellent diagnostic results [2, 3]. In the case of soleus muscle injuries, ultrasound has a very low diagnostic capability, and magnetic resonance imaging (MRI) should be used instead [4].

Because of the anatomical and functional complexity of the soleus muscle, there is no clear consensus on the directions to determine the prognosis of its lesions, despite the studies carried out to date [5–7]. In this context, our aim is to provide precise instructions to determine the prognosis of soleus muscle injuries.

✉ Carles Pedret
carles@carlespedret.com

1 Sports Medicine and Clinical Ultrasound Department, Clínica Diagonal, Esplugues de Llobregat, Spain

2 Consell Català de l'Esport, Generalitat de Catalunya, Barcelona, Spain

3 Medical Department of Football Club Barcelona, Barcelona, Spain

4 Medicine and Translational Research Program, Universitat de Barcelona, Barcelona, Spain

5 Department of Radiology, Hospital of Barcelona, Barcelona, Spain

6 Sports Medicine Unit, Hospital Clínic-Sant Joan de Déu, Barcelona, Spain

2 Anatomical Variability of the Soleus Muscle

The soleus muscle is not anatomically homogeneous. It has a particular anatomy with the proximal connective tissue arch from where the medial and lateral aponeurosis develop (MA and LA), and the central tendon (CT) [8]. The most important thing to keep in mind is that this anatomy, although considered as standard, is extremely variable. In fact, it can even vary between the two soleus muscles of the same person.

Two main aspects differentiate the anatomy of different soleus muscles: (1) the presence or absence of the aponeuroses and the CT, their length and location, and all their possible combinations (Fig. 1); and (2) the direction and pennation angles of the muscle fibres that are conditioned by this anatomical variability. These factors can be of great importance when planning RTP.

3 Muscular and Connective Dominance

Considering the large anatomical variability of the soleus muscle, we applied an individualised approach and performed an MRI to the calf region. The description relates to the soleus middle region (where all the aponeuroses are formed). Thus, we describe different types of soleus muscle (Fig. 2) on the basis of their muscular and connective dominance.

The muscular dominance is determined by the position of the CT, and this divides the soleus into two muscle volumes: one from the CT to the medial border, and another from the CT to the lateral border. Depending on the position of the CT (Fig. 2), one muscle volume will be bigger than the other, or the two volumes can be symmetrical (if the CT is in the middle). If there is no CT, there is no muscular dominance.

The connective dominance is determined by the length and thickness of the MA and the LA. Depending on the

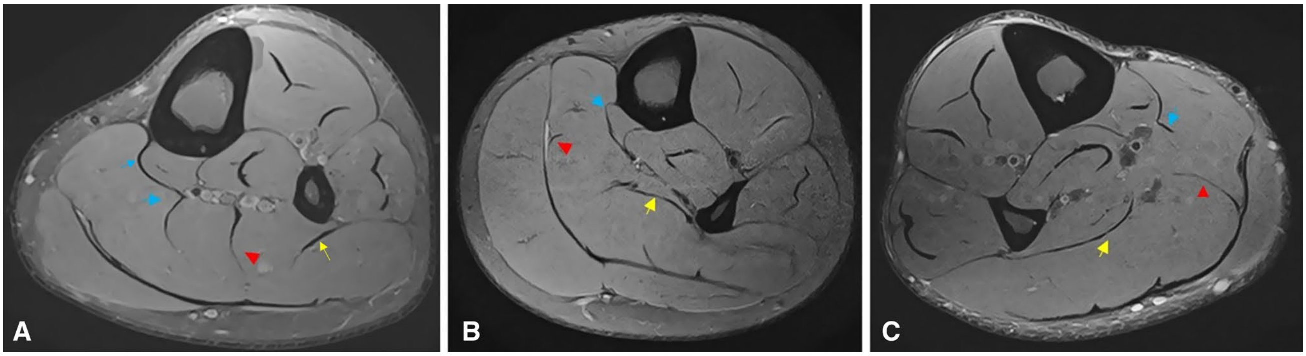

Fig. 1 MRI AX T2W FS as an example of different combinations of connective tissue (CT) distribution in the soleus muscle. **A** Lateralized CT (red arrowhead) with long peripheral and intramuscular medial aponeurosis (MA; blue arrows) and similar intramuscular lateral aponeurosis (LA; yellow arrow). **B** Medialized and hypoplastic CT (red arrowhead) with long LA (yellow arrow) and short MA (blue arrow). **C** Medialized CT (arrowhead) with large LA (yellow arrow) and short MA (blue arrow)

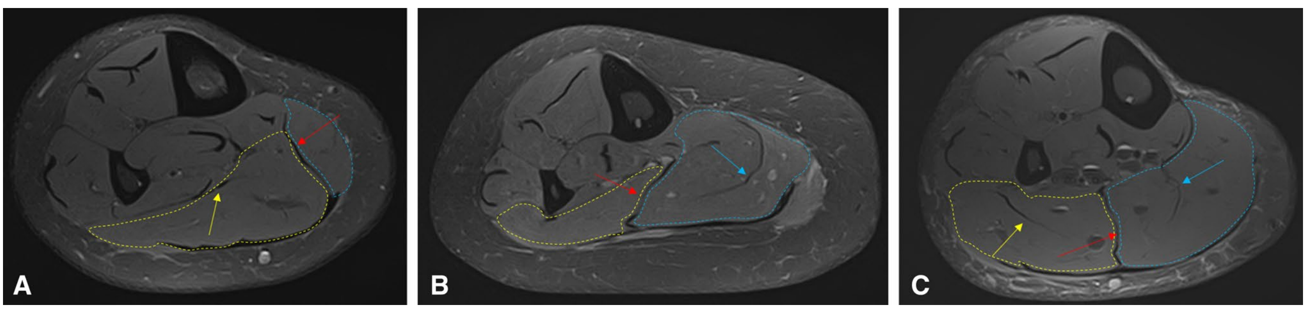

Fig. 2 MRI AX T2W FS as an example of different dominance types. The dotted yellow line indicates the lateral muscle volume of the soleus muscle and the dotted blue line the medial muscle volume. **A** Soleus muscle with a lateral muscle dominance and a lateral connective dominance. **B** Soleus muscle with a medial muscle dominance and a medial connective dominance. **C** Symmetrical soleus muscle. Central tendon red arrows, lateral aponeurosis yellow arrow), and medial aponeurosis blue arrows

predominance of the MA or LA or even their presence or absence, we speak about medial or lateral connective dominance.

- Symmetrical (in terms of muscle and connective tissue): CT in the middle, with the presence of a symmetrical MA and LA.
- With medial muscle dominance: CT on the lateral side. This means that most of the muscle volume is in the medial region.
- With lateral muscle dominance: CT on the medial side. This means that most of the muscle volume is in the lateral region of the soleus muscle.
- With non-muscular dominance: complete absence of CT, or presence of several hypoplastic ones (Fig. 1B).
- With medial connective dominance: MA longer and thicker than the LA and, most times, the CT.
- With lateral connective dominance: LA longer and thicker than the MA and, most times, the CT.

There is no non-connective dominance as far as we have seen. We found in all soleus muscles a medial and/or a lateral aponeurosis (this is why Table 1 shows 0% of non-connective dominance type).

During the years 2018–2021, we studied 107 soleus muscles by MRI, and their anatomical variability distribution is shown in Table 1.

4 Clinical Relevance

As previously described in the literature [2, 9, 10], the involvement of the connective tissue has a worse prognosis than the involvement of the muscle. In agreement with this, our preliminary results suggest that muscle dominance does not seem to have an impact on the prognosis of soleus muscle injuries, unlike connective dominance, which seems to have a worse prognosis in cases in which the injury is based on the dominant aponeurosis. In this context, the Prakash classification [9], which describes soleus muscle injuries on

Table 1 Anatomical variability of the 107 soleus muscles studied

Muscular dominance	
Symmetrical	50 (46.73%)
Medial muscular dominance	40 (37.38%)
Lateral muscular dominance	13 (12.15%)
Non-muscular dominance	4 (3.74%)
Connective dominance	
Symmetrical	49 (45.79%)
Medial connective dominance	46 (42.99%)
Lateral connective dominance	12 (11.22%)
Non-connective dominance	0 (0%)

the basis of the involvement of connective structures, is currently the one that most reflects reality.

However, to evaluate the prognosis of soleus muscle injuries, we must consider not only the involvement but also the distribution of connective aponeuroses, which conditions the direction and pennation angles of the muscle fibres. Ignoring this aspect is probably one of the main reasons why descriptive epidemiological series on soleus muscle injuries are not reliable and fail to find a reproducible prognostic pattern [5–7]. Indeed, classification systems would be more clinically relevant if they reflected the anatomical and functional roles of muscles as organs within a system, and offered a common nomenclature [11].

Finally, with our classification system (see Sect. 3), we provide directions for classifying soleus muscle injuries not only on the basis of the involvement, but also on the distribution, of connective tissue. For example, an injury affecting a short and hypoplastic CT could have a better prognosis than one involving a CT of a symmetrical soleus muscle in terms of RTP.

Further research is needed to reach a consensus on the use of the variables that we report in this article and the nomenclature, as well as to assess their application to RTP programs after soleus muscle injuries.

5 Conclusions

We draw the following conclusions:

- MRI is a useful tool to determine the exact structure of individual soleus muscles, and for early and accurate diagnosis of injuries.
- The soleus muscle has an enormous anatomical variability in the distribution of muscle volume and the amount and distribution of connective tissue.
- Using the combination of subtypes based on muscular and connective dominance can be a starting point to better understand the structure of the soleus muscle and reach a consensus on the way we classify every individual soleus.
- Soleus muscle injuries must be individually characterized. We can use general classifications of muscle injuries as a starting point, but then we must consider the specific subtype of soleus muscle.
- We must consider the great anatomical variability of the soleus muscle as a prognostic factor for injuries when planning the RTP. For example, an injury to a small and thin MA is not the same as an injury affecting a dominant MA. This way, we could plan an individualised and tailored treatment and rehabilitation protocol for each soleus injury and decrease the risk of reoccurrence.

Declarations

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Conflict of interest Carles Pedret, Ferran Rupérez, Sandra Mechó, Ramon Balius and Gil Rodas declare that they have no conflicts of interest relevant to the content of this article.

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Code availability No codes or software available.

Author contributions CP wrote and designed the article and future studies, FR analysed the data, SM reviewed all MRIs, RB designed the main study, GR reviewed the original manuscript. All authors read and approved the final manuscript.

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