

# CALF STRAIN IN ATHLETES

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## Abstract

» Calf strain is a common condition. In high-performance athletes, calf strain contributes to a substantial absence from competition.

» Player age and history of a calf strain or other leg injury are the strongest risk factors for calf strain injury and reinjury.

» Although the diagnosis is often clinical, magnetic resonance imaging and ultrasound are valuable to confirm the location of the strain and the grade of injury.

» Nonoperative treatment is effective for most calf strain injuries. Operative management, although rarely indicated, may be appropriate for severe cases with grade-III rupture or complications.

» Further investigation is necessary to elucidate the benefits of blood flow restriction therapy, deep water running, lower-body positive pressure therapy, platelet-rich plasma, and stem cell therapy for calf strain rehabilitation.

Calf muscle strain is one of the most common muscle injuries in high-performance athletes and contributes to substantial player downtime because of its high mean time to return to sport and occurrence during critical periods in the competitive season<sup>1-3</sup>. Published reports on lower-body muscle strain have provided frequent updates on the rehabilitation of high-profile muscle groups, such as the hamstring muscles, and improvements to calf strain management are seldom discussed despite the prevalence of these injuries in competitive sports. In this article, we discuss the diagnosis, treatment, outcomes, risk factors, and prevention of calf muscle strain in athletes.

## Epidemiology

First described in 1883, calf strain is also known as “tennis leg” due to its frequent occurrence in that sport<sup>4-7</sup>. Although the

seasonal injury incidence, defined as the number of injuries per team per season, is notable in tennis<sup>8-10</sup> (0.3 to 0.8), calf strains are not unique to tennis and have since been reported in numerous other professional and collegiate sports such as American football<sup>11,12</sup> (seasonal injury incidence, 2.1 to 2.3), Australian football<sup>13,14</sup> (1.8 to 2.9), basketball (1.2)<sup>15</sup>, and soccer (1.3 to 2.3)<sup>16-20</sup> (Table I). Calf injury is most prevalent among athletes 22 to 28 years of age, more frequently affects men, and presents as a recurrent injury in approximately 19% to 31% of cases<sup>3,13,16,19-24</sup>. Rehabilitation is generally conservative, with a recovery period that ranges from immediate return to play to multiple months of missed practice or playing time<sup>2,3,12,13,19</sup>.

The risk of injury to the individual triceps surae muscles appears to be somewhat sport-dependent. For example, isolated gastrocnemius strain is the

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predominant calf strain injury in American football, whereas isolated soleus strain is more common in Australian football (Table II)<sup>12,13,22</sup>.

Moreover, gastrocnemius strain is associated with high-intensity running, acceleration, and deceleration activities, whereas soleus strain is more likely to occur during steady-state running activities<sup>13</sup>. Differences between muscles with respect to biomechanical function or muscle fiber profiles may contribute to this observation<sup>13</sup>. The gastrocnemius, which flexes the leg at the knee and plantar flexes the foot at the ankle, is dense in fast-twitch muscle fibers

adapted for rapid contraction<sup>1,5,7,25</sup>. The soleus, which contributes to plantar flexion, is dense in slow-twitch muscle fibers adapted for postural control<sup>1,2,26,27</sup>.

### Pathophysiology

#### *Gastrocnemius Strain*

The classic pathogenesis of a gastrocnemius tear involves knee extension with sudden ballistic foot movement from dorsiflexion to plantar flexion<sup>1,6,7,28,29</sup>. When the gastrocnemius is maximally stretched, the immediate contraction of the tensioned muscle can abruptly rupture the medial head of the gastrocnemius at the my-

otendinous junction<sup>7,28</sup>. The medial head of the gastrocnemius is more prone to injury than the lateral head, possibly because the medial head contributes more to muscle activity<sup>23</sup>. Imaging studies have attributed a 2:1 ratio of tears to the medial head compared with the lateral head of the gastrocnemius<sup>30,31</sup>.

#### *Soleus Strain*

Soleus strain is an overuse condition from repetitive, passive dorsiflexion of the foot with the knee bent<sup>23,29</sup>. In runners, this posture is observed while running uphill<sup>23,29</sup>. Because the

**TABLE I Incidence of Calf Strains in Professional and Collegiate Sports\***

| Study                          | Study Design              | Sample                                                                 | Seasonal Injury Incidence† | Injuries per 1,000 Match Hours | Study Duration            |
|--------------------------------|---------------------------|------------------------------------------------------------------------|----------------------------|--------------------------------|---------------------------|
| American football              |                           |                                                                        |                            |                                |                           |
| Mack <sup>11</sup> (2020)      | Descriptive epidemiology  | Athletes from 32 National Football League teams                        | 2.1                        | NA                             | 4 seasons (2015 to 2019)  |
| Werner <sup>12</sup> (2017)    | Retrospective case series | Athletes from 1 National Football League team                          | 2.3                        | NA                             | 12 seasons (2003 to 2015) |
| Australian football            |                           |                                                                        |                            |                                |                           |
| Green <sup>13</sup> (2020)     | Descriptive epidemiology  | Athletes from 16 Australian Football League clubs                      | 2.9                        | NA                             | 4 seasons (2014 to 2017)  |
| Orchard <sup>14</sup> (2013)   | Descriptive epidemiology  | 4,492 athletes from the Australian Football League                     | 1.8                        | 1.5                            | 20 seasons (1992 to 2012) |
| Basketball                     |                           |                                                                        |                            |                                |                           |
| McKay <sup>15</sup> (2001)     | Prospective cohort        | 190 elite and recreational Australian basketball athletes              | NA                         | 1.2                            | 2 seasons (1991 to 1992)  |
| Soccer‡                        |                           |                                                                        |                            |                                |                           |
| Nilstad <sup>16</sup> (2014)   | Prospective cohort        | 173 athletes from 12 elite Norwegian soccer clubs                      | 2.3                        | 2.0                            | 1 season (2009)           |
| Häggglund <sup>17</sup> (2013) | Prospective cohort        | 1,401 athletes from 26 elite European soccer clubs across 10 countries | 1.3                        | NA                             | 9 seasons (2001 to 2010)  |
| Bengtsson <sup>18</sup> (2013) | Prospective cohort        | 621 athletes from 27 elite European soccer clubs across 10 countries   | NA                         | 1.1                            | 11 seasons (2001 to 2012) |
| Ekstrand <sup>19</sup> (2011)  | Prospective cohort        | 2,299 athletes from 51 elite European soccer clubs                     | 2.0                        | NA                             | 8 seasons (2001 to 2009)  |
| Faude <sup>20</sup> (2006)     | Prospective cohort        | 143 athletes from 12 German national league soccer teams               | 1.6                        | NA                             | 1 season (2003 to 2004)   |
| Tennis                         |                           |                                                                        |                            |                                |                           |
| Dakic <sup>8</sup> (2018)      | Prospective cohort        | 52 athletes from the Australian Open                                   | NA                         | 4.5                            | 1 season (2015)           |
| Colberg <sup>9</sup> (2015)    | Prospective cohort        | 58 athletes from 4 collegiate tennis teams                             | 0.8                        | NA                             | 1 season                  |
| Winge <sup>10</sup> (1989)     | Prospective cohort        | 89 athletes from 13 elite Danish tennis teams                          | 0.3                        | NA                             | 1 season (1984)           |

\*NA = not available. †Seasonal injury incidence is defined as the number of calf strain injuries per team per season. ‡This sport is referred to as “football” in most countries outside the United States.

TABLE II Incidence of Gastrocnemius, Soleus, and Plantaris Strains in Professional Sports\*

| Study                                             | Study Design              | Sample                                                          | Gastrocnemius Strain | Soleus Strain | Plantaris Strain | Other†     |
|---------------------------------------------------|---------------------------|-----------------------------------------------------------------|----------------------|---------------|------------------|------------|
| American football<br>Werner <sup>12</sup> (2017)  | Retrospective case series | Athletes from 1 National Football League team for 12 seasons    | 20 (74.1%)           | 4 (14.8%)     | NA               | 3 (11.1%)  |
| Australian football<br>Green <sup>13</sup> (2020) | Descriptive epidemiology  | Athletes from 16 Australian Football League clubs for 4 seasons | 17 (11.8%)           | 126 (87.5%)   | 1 (0.7%)         | NA         |
| Waterworth <sup>22</sup> (2017)                   | Retrospective case series | 63 athletes from the Australian Football League for 5 seasons   | 8 (12.7%)            | 32 (50.8%)    | NA               | 23 (36.5%) |

\*NA = not available. †Other includes disruptions to the tibialis posterior, peroneus longus, or Achilles tendon, as well as concomitant tissue disruption for which a primary tissue injury was not specified.

mechanism for soleus rupture is associated with overuse, a soleus injury is subacute, with a gradual and cumulative effect, although acute strain can manifest in fatigued athletes<sup>23,32</sup>.

#### Plantaris Strain

Although relatively rare, an isolated rupture of the plantaris muscle can occur at the proximal muscle belly or the midportion of the plantaris tendon<sup>5,29</sup>. The pathogenesis is similar to that of a gastrocnemius tear and involves knee extension with ballistic foot plantar flexion<sup>23</sup>. Athletes with isolated lesions can retain a full range of motion without reduction in strength<sup>29</sup>. However, a plantaris injury is more often diagnosed concomitant with traumatic knee injury, such as lesions of the anterior cruciate ligament or the posterolateral corner<sup>5</sup>.

#### Presentation

An acute strain of the gastrocnemius can present with an audible pop at the onset of the injury, followed by dull to severe pain and swelling in the posterior lower limb within 24 hours<sup>1,6,28</sup>. The pain can be latent at the time of the injury, manifesting only after the athlete tries to stand, walk, or plantar flex the foot<sup>28,33</sup>. Individuals are often unable to perform a heel raise on the affected side because of compromised plantar flexion<sup>6</sup>. Palpation may identify tenderness at the muscle insertion into the Achilles tendon or, in more severe cases, a subcutaneous defect in the medial gastrocnemius from muscle

retraction<sup>1,6,7,23,28</sup>. In addition, mild to severe ecchymosis can appear at the rupture site<sup>23,28</sup>.

In contrast to gastrocnemius strains, soleus strains are typically subacute and present with muscle tension and tightness, gradual pain development over the course of days to weeks, and mild swelling and disability<sup>1</sup>. Palpation may identify tenderness deep within the lateral calf and distal to the gastrocnemius muscle bellies<sup>1,23</sup>. Soleus muscle contraction can be evaluated with the knee in maximal flexion, in which case the soleus becomes the primary contributor to plantar flexion. Imaging is recommended to identify potential concomitant ruptures of both the gastrocnemius and the soleus<sup>1,27</sup>.

An isolated plantaris strain is rare and can be clinically indistinguishable from a gastrocnemius strain, requiring imaging for a definitive diagnosis<sup>1</sup>. Plantaris rupture can present with an audible pop at the onset of the injury, and athletes with isolated lesions may retain a full range of motion without reduction in strength<sup>23,29</sup>. More often, plantaris strain is concomitant with traumatic lesions of the knee, such as those involving the anterior cruciate ligament or posterolateral corner<sup>5</sup>.

#### Differential Diagnosis

Within the triceps surae, ruptures are possible in the medial or lateral gastrocnemius, soleus, or plantaris muscles, and concomitant injuries of the gastroc-

nemius and soleus occur in 17% of cases<sup>1,27</sup>. Moreover, defects in the triceps surae can present with symptoms similar to those of thrombophlebitis, posterior compartment syndrome, popliteal artery entrapment syndrome, a torn Achilles tendon, or a ruptured Baker's cyst<sup>6,7,28</sup>. Tenderness in the medial gastrocnemius belly can be normal and is common even in uninjured athletes<sup>34</sup>. Posterior leg pain can also be referred from defects in other muscles, such as the popliteus, peroneus longus, and other deep posterior compartment or lateral compartment muscles. Physical examination and imaging are useful to confirm the differential diagnosis and inform the best treatment strategy.

#### Physical Examination

Palpation, strength testing, and passive flexion and extension of the knee and ankle joints are effective methods to identify areas of tenderness, tightness, swelling, and, in more severe cases, subcutaneous gaps or masses<sup>1,6,7,23,28</sup>. Tenderness in the medial gastrocnemius belly or the musculotendinous junction indicates gastrocnemius strain, the most common calf injury, and tenderness distal and lateral to the gastrocnemius implicates the soleus<sup>1,23</sup>. A palpable defect indicates a possible muscle retraction with complete fiber disruption. Palpable contractions that are spasmodic and involuntary indicate muscle cramps<sup>35</sup>.

As previously mentioned, athletes with gastrocnemius defects are often

unable to perform a heel raise on the affected side because of compromised plantar flexion<sup>6</sup>. Muscle contraction can be evaluated with the knee in maximal extension, which isolates the contribution of the gastrocnemius to plantar flexion<sup>1</sup>. Conversely, the soleus can be evaluated with the knee bent from 90° to maximal flexion, which makes it the primary contributor to plantar flexion<sup>1</sup>. Thus, close attention to knee posture can improve the accuracy of strength tests and inform the diagnosis.

Achilles tendon pathology is also a concern for clinicians. Achilles tendon rupture is best evaluated with the Simmonds triad, which includes the Simmonds-Thompson calf squeeze test, the Matles angle-of-declination test, and palpation for tendon defects near the insertion into the calcaneus<sup>1,36</sup>. A comparative study showed that positive results on at least 2 of the 3 tests provided confirmation of Achilles tendon rupture in all cases, which indicates high sensitivity for the Simmonds triad<sup>36</sup>.

### Imaging

Although the diagnosis of calf strain is often based on clinical findings, imaging is valuable to confirm the location of the strain and the grade of the injury<sup>1,7</sup>. This information guides the choice and duration of rehabilitation and influences return-to-play considerations, which

may have financial and strategic consequences for professional teams<sup>1,6</sup>. Musculoskeletal ultrasound and magnetic resonance imaging (MRI) are appropriate imaging modalities in the context of calf strain injury and have the additional benefit of detecting intramuscular fluid collection, which is associated with delayed return to play<sup>1,6,7,12,28</sup>.

MRI is an accurate and reliable method for examining muscle fiber integrity and continuity. It can differentiate gastrocnemius strain from other soft-tissue injuries, such as soleus strain or Achilles tendon pathology, and can evaluate the integrity of surrounding connective tissue<sup>2,7,28,32</sup>. Connective tissue defects are often associated with longer rehabilitation time than muscle tears alone, and studies have identified additional MRI characteristics as indicators for return to play, making MRI useful for the continual evaluation of recovery for professional athletes<sup>2,12,13,22,28,32</sup>. Moreover, fluid-sensitive MRI can reveal edema, hemorrhage, and hematoma<sup>7</sup>.

Ultrasound is often considered for its affordability, accessibility, and convenience<sup>1,7,29,37,38</sup>. Although no direct comparison of ultrasound and MRI diagnostic accuracy is available for calf strain, a comparison of the imaging modalities in the evaluation of hamstring strain found no significant difference<sup>39</sup>. Ultrasound can provide a differential

diagnosis for partial-thickness and full-thickness calf strains and is useful for evaluating edema, hemorrhage, hematoma, and thrombophlebitis<sup>7,28</sup>. Doppler ultrasound can readily detect deep vein thrombosis, which is sometimes concomitant with gastrocnemius strain<sup>7,28</sup>. Ultrasound is particularly convenient for its short imaging time, dynamic visualization, and easy comparison with the contralateral, uninjured leg<sup>38</sup>. However, there are no guidelines that define specific ultrasound characteristics as indications for return to play in professional sports.

### Grades

Calf strain is graded on the basis of physical and imaging parameters (Table III). A grade-I (mild) strain is associated with micro-tears in muscle fibers that cause mild pain or soreness but minimal reduction in strength and range of motion<sup>1</sup>. A grade-II (moderate) strain corresponds to a partial muscle tear that causes appreciable reduction in strength and range of motion. Athletes with partial tears are sometimes unable to walk and often have pain and swelling from edema or hemorrhage<sup>1</sup>. A grade-III (severe) strain signifies complete rupture, which presents with severe pain and disability, loss of muscle function, and extensive edema and hemorrhage<sup>1</sup>.

TABLE III Grades of Injury in Calf Strains and Recovery Times<sup>1,2,42</sup>

| Grade         | Presentation                                                                                   | Pathology                                            | Management                | Recovery*                                                                    |
|---------------|------------------------------------------------------------------------------------------------|------------------------------------------------------|---------------------------|------------------------------------------------------------------------------|
| 0             | Tenderness or swelling with no reduction in strength or range of motion                        | Edema or fluid adjacent to intact muscle fiber       | Conservative              | 0 to 2 weeks                                                                 |
| I (mild)      | Mild pain, tenderness, and swelling; minimal reduction in strength and range of motion         | Micro-tears with <10% muscle fiber disruption        | Conservative              | 1 to 4 weeks                                                                 |
| II (moderate) | Moderate pain, tenderness, and swelling; reduction in strength and range of motion             | Partial tear with 10% to 50% muscle fiber disruption | Conservative              | 2 to 5 weeks                                                                 |
| III (severe)  | Severe pain and disability with complete loss of muscle function; palpable subcutaneous defect | Complete tear with >50% muscle fiber disruption      | Conservative or operative | 5 to 10 weeks for conservative treatment or 24 weeks for operative treatment |

\*Recovery times are sport-dependent.

## Management

Nonoperative management is effective for most calf strain injuries. Treatment generally consists of rest, ice, compression, elevation, and nonsteroidal anti-inflammatory drugs (NSAIDs) in the acute phase, followed by appropriate stretches and exercise in the subacute phase<sup>1,6,7,23,28</sup>. A delayed progression from the acute phase to the subacute phase should trigger reevaluation for intramuscular hematoma or extensive tissue damage<sup>40</sup>. Operative treatment, although rarely indicated, may be considered in more severe cases with complete grade-III rupture or complications<sup>1,6,7,28,41</sup>. Another common event in athletes is exercise-induced muscle cramps, which can be alleviated with passive stretches of the calf muscle<sup>35</sup>. The utility and evidence for blood flow restriction therapy, deep water running, lower-body positive-pressure therapy (LBPPT), platelet-rich plasma, and stem cell therapy are discussed as well.

### Acute Phase

In the acute phase, treatment is designed to protect the injured tissue by reducing activity, managing pain, and preventing hemorrhage or other complications<sup>1,7,23</sup>. This is accomplished with rest, ice, compression, elevation, and NSAIDs<sup>1,6,7,23,28</sup>. In the first 24 to 72 hours, activities should be limited to allow the injured leg to be rested in an elevated position and NSAID use should be carefully managed to prevent bleeding from antiplatelet effects<sup>1,6,7</sup>. Alternatively, acetaminophen and celecoxib, which do not interfere with platelet function, may be used for pain management<sup>1</sup>. Cryotherapy, ice packs, compression bandages, and neoprene sleeves may be used to manage symptoms and to facilitate early ambulation<sup>1,6,7,23,34</sup>. High compression bandages that exert 20 to 30 mm Hg of pressure have been recommended in published reports, and some evidence has suggested that compression bandage use can improve recovery by up to 7 days<sup>6,23</sup>. Crutches, boots, or heel lifts may be used to protect the injured area and control pain<sup>1,7,23</sup>. Soft-tissue massage and

moist heat application are generally contraindicated in the acute phase as these techniques increase the risk of hemorrhage<sup>1,7</sup>.

### Subacute Phase

In the subacute phase, the body repairs the soft-tissue damage and forms scar tissue. Treatment is designed to restore mobility, prevent muscle atrophy or contracture, and guide tissue regeneration to optimize functional improvement<sup>28</sup>. Rehabilitation includes passive and active stretches, soft-tissue techniques, muscle strengthening, and proprioception exercises for 2 weeks, followed by general and sport-specific reconditioning exercises<sup>1,6,7,28</sup>. Stretching elongates the intramuscular scar tissue in preparation for strengthening exercises, and altering the degree of knee flexion can isolate the gastrocnemius and soleus during stretches<sup>1,28</sup>. Soft-tissue techniques such as low-level laser therapy, therapeutic ultrasound, electrical stimulation, and friction massage are also appropriate<sup>1,7</sup>. As range of motion improves and pain subsides, strength training can progressively incorporate isometric, isotonic, and dynamic exercises as tolerated without pain<sup>1,7,28,40,42</sup>. Finally, general and sport-specific reconditioning helps to restore strength and agility<sup>7,28</sup>.

### Operative Management

The mainstay of treatment is nonoperative. Operative management, although rarely indicated, may be considered in the most severe cases with complete grade-III ruptures, contractures, fibrosis, substantial hematoma, acute compartment syndrome, or myositis ossificans<sup>1,6,7,28,40,41</sup>. In cases of complete muscle rupture, the inability to stand on the metatarsal heads of the leg with a calf strain has been described as an indication for a surgical procedure<sup>41</sup>. Cheng et al. published a surgical technique for complete gastrocnemius rupture<sup>41</sup>. Surgical intervention reconstructs anatomical structures and removes fibrous scar tissue<sup>41</sup>. Postoperative management includes use of a compression

bandage to immobilize the repaired muscle and ambulation with crutches. The patient is non-weight-bearing for the first 4 to 6 weeks and then weight-bearing with progression to physical therapy<sup>40</sup>. Recovery from the surgical procedure is gradual over the course of 6 months<sup>42</sup>.

### Other Therapies

Additional therapies for muscle rehabilitation include blood flow restriction therapy (BFRT), deep water running, LBPT, and nascent therapies such as platelet-rich plasma, and, to a limited extent, stem cell therapy.

BFRT involves light resistance training with the use of a restriction band proximally on the extremity to occlude venous blood outflow while maintaining arterial blood inflow. Light resistance training exerts mechanical stress on the muscles, and the use of a restriction band induces tissue hypoxia and stimulates anaerobic metabolism<sup>43-45</sup>. Research has demonstrated that BFRT can increase muscle strength, hypertrophy, and angiogenesis compared with unrestricted light resistance training, but less muscle is recruited compared with unrestricted heavy resistance training<sup>43-48</sup>. Although the biological mechanism is unknown, in theory, the combination of mechanical and metabolic stress is thought to facilitate cellular signaling pathways that lead to protein synthesis, fast-twitch muscle fiber recruitment, and stimulation of myogenic stem cells<sup>43-45</sup>. Because heavy resistance training is often contraindicated in the early stages of recovery, BFRT may be useful as a progressive rehabilitation method to promote the regeneration and healing of muscle<sup>43,44</sup>.

Hydrotherapy techniques such as deep water running can be considered for muscle rehabilitation. Aquatic exercise has been practiced since the Romans first described the use of hydrotherapy to manage orthopaedic conditions<sup>49</sup>. Hydrotherapy uses the buoyancy, viscosity, and hydrostatic pressure of water to counterbalance gravity and provide resistance and compression<sup>50,51</sup>. Deep water running is one technique for weight-supported aerobic training, in

which the body is partially submerged in water. The upward buoyant force, which is equal to the weight of water that the body displaces, acts in opposition to the downward force of gravity<sup>50-53</sup>.

Thus, submersion up to various body parts offloads body weight: by 40% up to the hip, by 50% up to the waist, by 60% up to the sternum, or by 85% up to the shoulders<sup>50-53</sup>. The depth of immersion can be controlled using the slope of the pool, flotation equipment, or hydrotherapy treadmills that encapsulate users in aquatic cabins made of glass<sup>50</sup>. Deep water running has 2 forms: a high-knee style (high-knee deep water running) with stair-stepping movements, and a cross-country style (cross-country deep water running) with kinematics similar to treadmill running<sup>51</sup>. Both high-knee deep water running and cross-country deep water running have been observed to reduce gastrocnemius activation in comparison with treadmill running<sup>54,55</sup>. An environment that reduces muscle activation allows for active recovery with a decreased risk of reinjury<sup>50,51</sup>.

LBPPT has emerged as a popular alternative to hydrotherapy and other weight-supported rehabilitation methods. Lower-body positive-pressure treadmills, such as the AlterG, allow for weight-supported exercise in which users can designate the percentage of their body weight to be borne by the treadmill in addition to adjustments for speed and incline<sup>56-58</sup>. Users wear neoprene shorts that secure to a positive air pressure chamber of the treadmill. The differential air pressure of the chamber produces a variable force that lifts users, thereby decreasing the impact of gravitational forces and body weight during exercise<sup>56</sup>. Published reports on LBPPT have associated it with improved muscle functionality and posture in patients with muscular dystrophy and earlier postoperative return to sport in athletes<sup>58</sup>. Although LBPPT has not been studied in the context of muscle strain, LBPPT has demonstrated a linear reduction of gastrocnemius and soleus muscle activation in healthy individuals in relation to the amount of body weight

unloaded during exercise<sup>57</sup>. The reduction in muscle activation is similar to that achieved with deep water running at a matched stride frequency<sup>59</sup>. Furthermore, modifications that decrease the treadmill speed and/or incline also lessen gastrocnemius and soleus muscle activation<sup>56</sup>. For this protective reason, published reports have suggested LBPPT as an option for patients commencing a rehabilitation program and as an alternative to hydrotherapy<sup>56,57</sup>.

Platelet-rich plasma is an autologous, platelet-rich blood product obtained from the centrifugation of whole blood. Platelets are purported to release growth factors and cytokines that facilitate the regeneration and healing of muscle tissues<sup>60-63</sup>. Presently, 1 study has examined platelet-rich plasma treatment in the calf muscles. In a retrospective evaluation of patient outcomes, Borriore et al. reported that early ultrasound-guided platelet-rich plasma treatment of grade-II and III gastrocnemius strain reduced pain, discomfort, and recovery time compared with the standard conservative treatment<sup>63</sup>.

However, the patient sample was limited to recreational sport athletes older in age than elite athletes engaged in competitive sports<sup>63</sup>. Level-I studies investigating platelet-rich plasma application in other muscle groups have shown inconsistent evidence<sup>60-62</sup>; in the case of the hamstring muscles, A Hamid et al.<sup>64</sup> reported that platelet-rich plasma facilitated a faster recovery with a shorter time to return to play, and Reurink et al.<sup>65</sup> and Hamilton et al.<sup>66</sup> observed no significant differences in the time to return to play or the reinjury rate between platelet-rich plasma and control cohorts. Thus, additional investigation is necessary to elucidate the benefits of platelet-rich plasma for muscle rehabilitation.

The therapeutic implications of stem cell therapy are still preliminary but demonstrate some potential for muscle rehabilitation. Stem cell therapy aims to restore the structural integrity and functionality of skeletal tissue by stimulating muscle fiber development and vascularization<sup>67-69</sup>. In animal models,

stem cell therapy has demonstrated accelerated muscle recovery with improved angiogenesis and reduced scar tissue formation<sup>69,70</sup>. Stem cell therapy has been investigated in a limited number of clinical trials and primarily for the treatment of muscular dystrophies and incontinence disorders<sup>69,71</sup>. In these clinical trials, patients who received transplantation or intra-arterial infusion of progenitor cells such as mesenchymal stromal cells, mesoangioblasts, or myoblasts cultured from muscle satellite cells had outcomes that ranged from no difference in muscle histology and/or functionality to improvements in these measures<sup>69,71</sup>. The differences across published reports are partly attributable to variations in study methodology, small patient samples, and an incomplete understanding of the biological mechanisms stimulated by stem cell therapy. Future research may provide more evidence for the use of stem cell therapy in muscle rehabilitation.

### Return to Play

Most calf strains recover well under conservative treatment; the muscle develops a small fibrous scar without pharmacological or surgical interventions<sup>28,40</sup>. Full recovery is indicated by symptom relief and the return of strength, flexibility, and range of motion comparable with those of the contralateral side<sup>1,34</sup>. Early diagnosis and treatment of muscle strain can ameliorate the severity and duration of the injury, and limited evidence has suggested that treatment within 48 hours of an injury facilitates earlier return to play<sup>1,28,34,40</sup>. Although return to play is often mediated by sports-specific considerations, a general benchmark to begin sports reconditioning is ambulation without pain<sup>6,7,72</sup>. Premature exertion can delay recovery, can cause incomplete healing, and can increase the risk of reinjury<sup>1,13</sup>.

### MRI Correlation

MRI is useful to evaluate professional return to play<sup>2,12,13,22,28,32</sup>. Certain imaging characteristics, such as the severity and the site of the injury, are

associated with a longer recovery time. Higher grades of tissue injury generally require longer rehabilitation (Table III). Concomitant connective tissue disruption has been associated with longer time to return to play in elite runners and Australian football, soccer, rugby, and hockey athletes with calf strain<sup>2,13</sup>. Connective tissues such as tendons, aponeuroses, and epimysium are integral to muscle support and function but heal more slowly than muscle when disrupted<sup>2,22</sup>. Injury location may also play a role in recovery time. Although gastrocnemius and soleus strains have similar recovery times, the location of the tear within the tissue and the presence of aponeurotic disruption may influence overall recovery<sup>2,24</sup>. Soleus strains in which the musculotendinous junction or tendon are implicated correspond to more missed games<sup>22</sup>. In addition, ruptures in the central aponeurosis recover more slowly than those in the lateral or medial aponeurosis and myofascial sites<sup>24,32,73</sup>. In gastrocnemius strains, tears in the anterior aponeurosis and distal myotendinous junction correlate with higher-grade injuries, which require longer rehabilitation<sup>2</sup>.

### Other Considerations

Other considerations for return-to-play decisions include the manner and history of the injury. A study of elite Australian football players showed that calf strains from running activities corresponded to longer recovery periods than calf strains from non-running activities, irrespective of the muscle injured<sup>13</sup>. Running activities such as high-intensity and steady-state running, acceleration, deceleration, or sudden change of direction may be associated with more tissue disruption of the muscle-tendon unit<sup>13</sup>. Player reinjuries are another concern for sports managers as calf strain is a recurrent injury in approximately 19% to 31% of cases<sup>3,21,24</sup>. Reinjuries are associated with longer rehabilitation times and often involve older, more experienced players<sup>13</sup>. Premature return to play increases the risk of reinjury as tissues have not completely healed<sup>1,13</sup>. How-

ever, the degree of tissue damage in reinjuries compared with the index injuries is subject to debate. Studies of hamstring strain have shown greater muscle damage in reinjuries than in index injuries, which may explain the prolonged recovery time in reinjuries<sup>74</sup>. However, conflicting evidence of similar muscle damage between reinjuries and the index injuries also exists<sup>74</sup>. An appropriate rehabilitation timeline may consider other contextual factors as well, such as sport-specific demands, player position, seasonality, and athlete psychology<sup>24</sup>.

### Risk Factors

Player age and history of a calf strain or other leg injury are the strongest risk factors for calf strain in elite athletes, and player characteristics such as height, weight, sex, and side dominance are unlikely to be associated with calf muscle injury<sup>3,13,16,17,19,20,75</sup>. A possible explanation is that age-related tissue changes involve progressive declines in skeletal muscle quality and function, the consequences of which include neuromuscular maladaptations that restrict muscle force and rate of contraction<sup>3</sup>. In some cases, the rehabilitated tissue has suboptimal functionality compared with the contralateral, uninjured side<sup>76</sup>. Because optimal tissue functionality is protective, this suggests that a previous muscle injury can be a risk factor for a future injury. Prior injuries in the calf, hamstrings, quadriceps, adductors, and knee have been identified as risk factors for a subsequent calf injury<sup>3,16</sup>. More limited evidence has shown that increased body mass index and preseason activity are risk factors for calf strain<sup>3,16</sup>.

### Prevention

Studies have indicated that pre-participation stretching improves range of motion and muscle compliancy, which may be protective against muscle strain<sup>77</sup>. Although stretching promotes muscle performance in elastic movements such as hops or leaps, it is associated with decreased muscle power in predominantly concentric contractions such as steady-state cycling or jogging<sup>77,78</sup>. For this rea-

son, the benefits of stretching alone are unclear. However, dynamic and sport-specific pre-participation drills may be able to restore stretch-induced performance loss when coupled with a stretching routine appropriately tailored for the player position<sup>77</sup>. Because the strongest risk factors for calf strain are unmodifiable, the prevention of calf strain is best accomplished with pre-participation stretching and warm-up exercises that increase flexibility and agility in the tissues most at risk for injury<sup>34,77</sup>.

### Conclusions

Calf muscle strain is a common condition. In high-performance athletes, calf strain contributes to missed practice or playing time in many professional and collegiate sports. Timely diagnosis and treatment can improve outcomes and can facilitate earlier return to sport. Although the diagnosis can be made by clinical examination, MRI and ultrasound are both appropriate imaging modalities to confirm calf strain. MRI may additionally be useful in the evaluation of recovery time as return-to-play decisions often have financial and strategic consequences for professional teams. Conservative treatment is effective for most calf strain injuries. Operative management, although rarely indicated, may be appropriate in severe cases with grade-III ruptures or complications. Player age and history of a calf strain or other leg injury are the strongest risk factors for calf strain injury and reinjury. Athletes are encouraged to practice pre-participation stretching and warm-up exercises to maintain flexibility and agility for prevention of calf muscle injury.

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