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Calf muscle strain injuries in elite Australian Football players: a descriptive epidemiological evaluation

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EPIDEMIOLOGY OF CALF MUSCLE STRAIN INJURIES

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Running head: EPIDEMIOLOGY OF CALF MUSCLE STRAIN INJURIES

Abstract

Background: Calf muscle strain injuries (CMSI) show consistent rates of prevalence and re-injury in elite Australian Football players. An epidemiological evaluation is warranted to better understand the clinical presentation and recovery of CMSI.

Purpose: First, to describe the epidemiology of CMSI in elite Australian Football players. Second, to determine if recovery following injury is different according to: (i) injury type (index vs re-injury); (ii) muscle injured (soleus vs gastrocnemius); and, (iii) mechanism of injury (running-related activity vs non running-related activity).

Study design: Descriptive epidemiological.

Methods: Data retrieved from the Soft Tissue injury Registry of the Australian Football League were analysed. Sixteen clubs submitted data on CMSI from 2014-17. Data included: player characteristics, training and match history at the time of injury, MRI, and the time to reach recovery milestones.

Results: 184 CMSI were included (149 index injuries; 35 re-injuries). Soleus injuries were most prevalent (84.6%). Soleus injuries took 25.4 ± 16.2 days to return to play, whereas gastrocnemius injuries took 19.1 ± 14.1 days ($p=0.097$). CMSI sustained during running-related activities took approximately 12 days longer to recover than injuries sustained during non running-related activities ($p=0.001$). Compared to index injuries, re-injuries involved older players ($p=0.03$) and significantly more time was taken to run at $>90\%$ of maximum speed, return to full training, and return to play ($p \leq 0.001$). Almost all of the observed re-injuries involved soleus (91.4%).

Conclusion: Soleus injuries are more prevalent than gastrocnemius injuries in elite Australian Football players. Prognosis appears to be influenced by clinical factors, with CMSI sustained during running-related activities and re-injuries needing more time to recover.

KEYWORDS: soleus, gastrocnemius, injury, prognosis, sport, football

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1. INTRODUCTION

Calf muscle strain injuries (CMSI) are one of the most prevalent soft tissue injuries in the elite competition of Australian Football, the Australian Football League (AFL).^{1,2} Over the past ten AFL seasons there have been 1.3 to 3.7 new CMSI per team per season. The rate of same-season re-injury has ranged from 4% to 16%.² Injury rates in the AFL are comparable to what has been reported in other codes, such as elite soccer and American football.^{3,4}

The AFL premiership season has three distinct stages: (1) the preseason, commencing in late October or November; (2) the competition season, made up of 22 weekly matches that begin in late March; and (3) a four-week finals series. Matches are split into four quarters totalling approximately 120 minutes of which players typically participate in at least 80% of the total game time.^{5,6} Each team plays with 22 players across a variety of positions in the forward line, back line, and midfield. There are also players that are not specialised to any single position ('utility' players) as well as one specialised position (the 'ruck') reserved for a tall player who competes against the opposition ruck when the umpire re-starts play.⁵

Australian Football involves jumping and landing, as well as repeat bouts of running, all of which load the calf muscles. AFL players can exceed more than 13km of combined walking and running in a match, including ~4km of high intensity running (>5 m/s), peak sprinting speeds exceeding 8m/s, and more than 200 accelerations at high exertion.^{6,7} When running at a speed of 6m/s, the soleus and gastrocnemius collectively generate a peak force as high as 12.5 times body weight.⁸ Approximately two-thirds of this force can be attributed to the soleus due to its large physiological cross-sectional area. Recent musculoskeletal modelling studies have found that the calf muscles are the dominant contributors to upward and forward acceleration of the body's centre of mass (i.e., support and propulsion, respectively) for running at a range of steady state speeds^{9,10} as well as for maximum acceleration sprinting.¹¹ Given the high running demands of Australian Football and the importance of the calf muscles during running, the susceptibility of AFL players to CMSI is not surprising.

Nevertheless, little is known about the epidemiology and recovery time frames of CMSI when compared to other common muscle strain injuries (e.g. hamstring muscle strain injuries).

The injury burden of CMSI varies considerably, from no missed games to a recovery period of up to 95 days.^{12,13} Specific injury characteristics warrant consideration, such as the injury site^{14,15} as well as the presence and severity of connective tissue disruption.^{13,16} These characteristics can be determined from MRI, hence it is possible that baseline MRI findings may provide some insight regarding differences in recovery time frames following CMSI.^{13,15,16} Furthermore, clinical factors at baseline may explain some of the variation in the time taken to return to play (RTP), but the prognostic value of clinical factors for estimating recovery following CMSI requires further investigation.¹⁷

It is likely that intrinsic factors, such as strength, flexibility and functional capacity, as well as extrinsic factors, such as the stage of the season, the mechanism of injury, and whether it is a first time injury or a re-injury,¹⁷⁻¹⁹ play a role in the time that it takes to achieve recovery milestones and RTP following CMSI. It has not been possible to determine the impact of these factors from research to date since direct references to prognostic data and information regarding the characteristics of the injured athletes or the circumstances of injury are often lacking. The first aim of this study was to describe the epidemiology of CMSI in elite AFL players, including: (i) the cumulative incidence of injury per season; (ii) the characteristics of the injured players; and (iii) the training and match history immediately prior to the time when the injury occurred. The second aim was to determine if the recovery time frame following CMSI was influenced by the following clinical factors: (i) injury type (index vs re-injury); (ii) primary muscle injured (soleus vs gastrocnemius); and (iii) the mechanism of injury (running-related activity vs non running-related activity).

2. MATERIALS AND METHODS

2.1 Study procedure and cohort

The data analysed in this study were obtained from the Soft Tissue injury Registry of the Australian Football League (STRAFL). Data were gathered from 16 of the 18 clubs participating in the AFL where a standardised injury report was completed by club medical staff for CMSI that occurred over four consecutive seasons (2014 – 2017). Injuries were reported to the STRAFL any time that a club doctor and/or physiotherapist clinically diagnosed a player with a calf muscle strain injury where the injury resulted in time-loss or modification of training or time-loss from competition, without a history of blunt trauma.^{3,12}

The STRAFL recorded information for CMSI in four sections: (i) player demographics, including chronological age, height, weight, BMI, side dominance (kicking leg), playing age (the number of career games prior to injury), ethnicity (indigenous/ non-indigenous), lower leg injury history on the injured side (calf, ankle, foot), the primary field position of the player (forward line, back line, midfield, ruck, utility); (ii) information about the training history and matches played prior to the injury, including the stage of the season, whether the player had completed at least 80% of the pre-season, the proportion of each match that the player completed for at least 3 weeks preceding the injury; (iii) the injury circumstances, including the activity when the injury occurred (training, game, other), the timing of the injury within the match (the quarter of the match when the injury manifested, the total game time played, the number of continuous minutes played immediately prior to the injury), the mechanism of injury (acceleration, high intensity running, steady state running, sprinting with lumbar flexion, deceleration, rapid change of direction, stance leg while kicking, kicking leg while kicking, jumping, landing, gradual onset, nil-specific, other); and (iv) the outcomes following injury, including the number of days to reach four recovery milestones (pain free walking, running at >90% of maximum speed, full training, and RTP). In 85.3% of cases (n=157) an electronic copy of the MRI was available for analysis. MRIs were performed but were not accessible for 11.4% of cases (n=21), and there were 3.3% of cases (n=6) that did not have an MRI performed at all. The 14.7% of injuries without an available MRI were excluded from the analysis of the muscle injured. Ethical approval for this study was obtained from the Australian Football League Research Board and La Trobe University (HEC13-057). Written consent was obtained from all players included in the study.

2.2 Data analysis

2.2.1 Classification of injury as an index injury or a re-injury

All CMSI were classified as an index injury or a re-injury. An index injury was defined as a first time injury in the reported location for the injured side. A re-injury was defined as an injury that was in the same location as an index injury, and it occurred before or after RTP up to two seasons after the date of the index injury.^{18,20}

2.2.2 MRI assessment

All MRIs were de-identified prior to radiological assessment. Radiologists (ML, AR) were blinded to all clinical and outcome data. MRI was used in this study only to determine whether the lesion predominantly involved soleus, gastrocnemius, or other musculotendinous structures of the lower leg. If there was evidence of an injury to more than one structure, the

primary musculotendinous structure injured was defined as showing: (i) a larger injury, represented by greater craniocaudal length of oedema (mm), and/or, (ii) more extensive tissue disruption at the injury site. Eight cases (4.3%) were excluded because there was no macroscopic evidence of muscle strain injury.

2.2.3 Statistical methods

Descriptive statistics were used to provide an overview of the epidemiology of CMSI in the AFL and to generate frequency distributions for: (i) the cumulative incidence of injury per season; (ii) the characteristics of the injured players; (iii) the muscles injured; and (iv) training and match history at the time of injury. All continuous variables were not normally distributed and Mann-Whitney U tests were used to evaluate between-group differences in the time to reach recovery milestones for: (i) injury type (index vs re-injury); (ii) primary muscle injured (soleus vs gastrocnemius); and (iii) the mechanism of injury (running-related activity vs non running-related activity). To calculate the effect size (r) for these between-group comparisons the formula $r = z/\sqrt{n}$ was used. Effect size was categorized as small ($r \leq 0.1$), medium ($r = 0.30$), or large ($r \geq 0.50$).²¹ All analyses were performed using statistical software (SPSS v 24.0; Inc, an IBM Company, Chicago, Illinois) with the significance level set at $p < 0.05$.

3. RESULTS

3.1 Participants

Data for 149 different players who sustained at least one CMSI during the 4 year period were reported to the STRAFL and were included in the study. The median chronological age was 25 years (range: 18 to 33 years), playing age was 84.5 games (range: 0 to 299 games), height 187 cm (range: 168 to 203 cm), weight 84.5 kg (range: 70 to 108 kg), and body mass index 24.6 kg/m² (range: 19.7 to 28.2 kg/m²). Injuries were sustained by players in all positions, including the back line (31%), forward line (28.8%), midfield (27.7%), utility (8.2%), and the ruck (4.3%).

3.2 Overview of CMSI in the AFL

3.2.1 Rate and type of CMSI

A total of 184 CMSI were reported to the STRAFL between the start of the 2014 preseason and the end of the 2017 season (range: 41 to 51 CMSI per year)(Table 1). On average, there were 2.6 to 3.2 injuries per club per year and 46 total (index + recurrence) injuries per year. The 184 CMSI were made up of 149 index injuries (81% of all CMSI, 28 to 43 per year) and 35 re-injuries (19% of all CMSI, 6 to 13 per year). The cumulative incidence of re-injury was

players) and Koulouris *et al.*²⁸ (investigating a mixed cohort of people) found gastrocnemius injuries to be more prevalent than soleus injuries. The prevalence of soleus versus gastrocnemius injuries may be somewhat sport-dependent.

In the present study a running-related mechanism of injury (e.g. steady-state running, high-intensity running, acceleration) was commonly reported for CMSI (Figure 3A and 3B). This result is not surprising considering the mechanical function of the calf muscles during running. Of all the major lower-limb muscle groups, the soleus and gastrocnemius muscles combined have been reported to generate the largest forces during the stance phase of running.^{9,10} Force magnitudes as high as 9.5kN (or 12.5 times body weight) have been recorded during running at a speed of 6m/s from a force transducer surgically implanted around the Achilles tendon.⁸ Furthermore, recent ultrasound-based investigations have demonstrated that the soleus and gastrocnemius muscles experience an active stretch-shortening cycle throughout the stance phase of running: the contracting muscle fibres tend to shorten in length with the bulk of the observed muscle-tendon unit lengthening and shortening attributable to tendon stretch and recoil.²⁹⁻³¹ When interpreted together, these findings would suggest that for the soleus and gastrocnemius muscles during running the junction between the muscle fibres and tendinous tissues (where muscle strain injuries typically occur) is probably subjected to particularly large and rapid tensile loads on a repetitive basis. In support of this point, the mid stance period of running has previously been identified as the exact moment of injury when analysing the video footage of a gastrocnemius muscle strain that occurred when rapidly accelerating.³² Given that some elite Australian Football players average more than four hundred combined efforts of acceleration and high intensity running in a single match,⁵ it is easy to appreciate how running-related activities might challenge the tissue threshold of the calf muscles.

We found differences in the running-related activities resulting in injury when comparing soleus versus gastrocnemius injuries. Soleus injuries occurred more commonly during steady-state running whereas gastrocnemius injuries occurred more commonly during high intensity running. This observation is consistent with the long-held clinical belief about the differences in the mechanism of injury when comparing soleus and gastrocnemius,^{33,34} but to our knowledge no previous studies have presented data to substantiate this point. This observation might be explained by differences between muscles with respect to mechanical function (i.e., uniarticular versus biarticular role)³⁵ or muscle fibre profiles (e.g. slow twitch fibres represent up to 80.4% of soleus fibres,³⁶ whereas they comprise ~50% of gastrocnemius fibres).³⁷

We also found a considerable proportion of CMSI to occur without a readily identifiable inciting incident. Nearly half of all index injuries and around one third of re-injuries had a gradual onset or nil-specific mechanism of injury (Figure 3B). The absence of an inciting incident is in contrast to what is commonly observed for other lower-limb muscle strain injuries (e.g. hamstrings, rectus femoris, adductors). It therefore seems that many CMSI are not necessarily associated with an immediate and significant loss of function but instead may be better described as an evolving or cumulative condition. The absence of an inciting incident might be related to the precise anatomical location of injury and/or severity of tissue disruption, such as whether the injury primarily involves the epimysial layer versus injuries involving the intramuscular aponeuroses.^{16,17} Clearly, further research is warranted to explore whether the mechanism of injury is associated with specific injury characteristics.

Following CMSI, three of the four recovery milestones were delayed for soleus injuries compared to gastrocnemius injuries, albeit not significantly. The recovery time for soleus injuries in this study was similar to what has been reported previously; Pedret *et al.*¹⁴ reported an overall RTP timeframe of 29.1±18.8 days in a mixed cohort of athletes. Soleus injuries may require longer recovery time frames due to anatomical factors. Soleus has a complicated three-dimensional structure with extensive intramuscular and intermuscular aponeuroses that influence the tissue dynamics within the muscle as well as between soleus and gastrocnemius.³⁸⁻⁴⁰ It is possible that an injury to soleus disrupts the usual tissue dynamics and thus more time may be needed to restore tissue integrity before heavy loading can be tolerated.

The mechanism of injury may also influence the length of recovery following muscle strain injuries.^{17,41} Hamstring muscle strain injuries that occur during sprinting versus those that occur as a result of an over-stretch mechanism have been found to have different prognoses.^{42,43} In the present study, irrespective of the muscle injured, CMSI that occurred during running-related activities required longer recovery periods when compared to CMSI that occurred during non running-related activities. It is possible that running-related CMSI resulted in more extensive tissue damage or affected specific locations critical to the viable function of the muscle-tendon unit during the injurious activity. Following injury, a longer recovery period may be required for adequate tissue healing and to regain proficiency during the specific running activity that resulted in injury.^{42,44}

During a match AFL players can average more than 12 km in total distance, in which they are frequently accelerating, decelerating, and running at various speeds ranging from jogging to sprinting.^{5,7,22} These high loading demands could be a factor in the re-injuries observed in

this study. First, the majority of re-injuries occurred during running-related activities, with the most common injury mechanism being steady state running. Second, re-injuries almost exclusively involved the soleus, a muscle that is operating at near maximal capacity across a large range of running speeds.^{9,25,45} Third, over half of the re-injuries occurred within 2 months of the index injury, either during the rehabilitation period prior to RTP or within a short period after RTP. The cumulative incidence of re-injury in this study is similar to what has been reported previously for hamstring muscle strain injuries. Wangenstein *et al.* found 50% of re-injuries occurred within 50 days of the index injury.⁴⁶ Early muscle re-injuries may occur for a variety of reasons, but a common notion is that the compromised tissue is exposed to loads in excess of its current capacity.⁴⁷⁻⁴⁹ Early muscle re-injuries may occur because of incomplete tissue healing and persistent structural changes, including scar tissue, despite the resolution of clinical signs (e.g. range of motion, strength) and symptoms (e.g. pain, apprehension).^{47,50} Evidence for this scenario has recently been provided by Bayer *et al.*, who evaluated tissue healing following severe acute muscle strain injury, the majority of which were hamstring muscle strain injuries and CMSI.⁵¹ The extent of tissue inflammation and muscle atrophy was measured using MRI at baseline, three, and six months post-injury. They found tissue inflammation to remain elevated and atrophy of the injured muscle to persist for at least six months post injury. A relationship was apparent between the extent of the injury, the inflammatory response, and muscle atrophy (i.e., greater atrophy occurred with injuries that had an elevated inflammatory response).⁵¹ Finally, early muscle re-injuries may be attributable to extrinsic or contextual factors, such as positional demands, psychology, and pressure/expectations from coaching staff.⁵²

In this study re-injuries also involved significantly older players, which is consistent with previous findings that older age is one of the strongest risk factors for future CMSI.⁵³ One hypothesis is that increasing age could result in architectural or neurological mal-adaptations that predispose to future injury, but these relationships are yet to be formally evaluated. Re-injuries can pose a significant clinical challenge since, as evidenced in this study, they often require a prolonged recovery period relative to index injuries. For this reason every effort needs to be made to avoid them in the first place.^{19,50}

This study had some limitations that need to be acknowledged. First, a comparison of key metrics between players with and without CMSI involving the entire AFL cohort was not possible because the STRAFL is only permitted to collect data on injured players. Second, because reporting of CMSI to the STRAFL was voluntary, especially for injuries that occurred during the preseason, it is possible that the calculated number of CMSI per club per year underestimated the true incidence. Third, MRI studies were unavailable for some cases.

This limitation only involved a small number of cases that were removed from the analysis relating to the muscle injured. Finally, this study did not compare the detailed MRI features of the injuries. Future work is needed to determine whether or not specific characteristics evident on MRI relate to the prognosis for RTP or the risk of re-injury for CMSI.

5. PERSPECTIVES

CMSI, particularly soleus injuries, are common in elite Australian Football players. Knowledge regarding clinical factors, such as the type of injury (index vs re-injury) and the injury mechanism (running-related activity vs other presentations such as gradual onset, nil-specific, jumping, landing, kicking, other), may be of value in the assessment and management of CMSI.

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7. CONFLICT OF INTEREST

All authors (BG, ML, ASc, JM, ASe, AR, JC, TP) declare that they have no conflicts of interest related to the contents of this article.

Reference list:

- 1 Orchard J, Seward H, Orchard J. 2014 AFL Injury Report. Australian Football League (AFL) 2014:1-20.
- 2 Australian Football League. 2017 AFL Injury Survey. 2017:1-19.
- 3 Hallen A, Ekstrand J. Return to play following muscle injuries in professional footballers. *J Sports Sci* 2014;32:1229-1236.
- 4 Werner BC, Belkin NS, Kennelly S, Weiss L, Barnes RP, Potter HG, et al. Acute Gastrocnemius-Soleus Complex Injuries in National Football League Athletes. *Orthop J Sports Med* 2017;5:2325967116680344.
- 5 Gray AJ, Jenkins DG. Match Analysis and the Physiological Demands of Australian Football. *Sports Med* 2010;40:347-360.
- 6 Wisbey B, Montgomery PG, Pyne DB, Rattray B. Quantifying movement demands of AFL football using GPS tracking. *J Sci Med Sport* 2010;13:531-536.
- 7 Coutts AJ, Quinn J, Hocking J, Castagna C, Rampinini E. Match running performance in elite Australian Rules Football. *J Sci Med Sport* 2010;13:543-548.
- 8 Komi PV. Relevance of in vivo force measurements to human biomechanics. *J Biomech* 1990;23:23-34.
- 9 Dorn TW, Schache AG, Pandy MG. Muscular strategy shift in human running: dependence of running speed on hip and ankle muscle performance. *J Exp Biol* 2012;215:1944-1956.
- 10 Hamner SR, Delp SL. Muscle contributions to fore-aft and vertical body mass center accelerations over a range of running speeds. *J Biomech* 2013;46:780-787.
- 11 Debaere S, Delecluse C, Aerenhouts D, Hagman F, Jonkers I. Control of propulsion and body lift during the first two stances of sprint running: a simulation study. *J Sport Sci* 2015;33:2016-2024.
- 12 Ekstrand J, Hagglund M, Walden M. Epidemiology of Muscle Injuries in Professional Football (Soccer) *Am J Sports Med* 2011;39:1226-1232.
- 13 Prakash A, Entwistle T, Schneider M, Brukner P, Connell D. Connective tissue injury in calf muscle tears and return to play: MRI correlation. *Br J Sports Med* 2017;52:929-933.
- 14 Pedret C, Rodas G, Balias R, Capdevila L, Bossy M, Vernooij RWM, et al. Return to Play After Soleus Muscle Injuries. *Ortho J Sports Med* 2015;3:2325967115595802.

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- 15 Waterworth G, Wein S, Gorelik A, Rotstein AH. MRI assessment of calf injuries in Australian Football League players: findings that influence return to play. *Skeletal Radiol* 2017;46:343-350.
- 16 Balias R, Alomar X, Pedret C, Blasi M, Rodas G, Pruna R, et al. Role of the Extracellular Matrix in Muscle Injuries: Histoarchitectural Considerations for Muscle Injuries. *Orthop* 2018;6:1-3.
- 17 Valle X, Alentorn-Geli E, Tol JL, Hamilton B, Garrett WE, Pruna R, et al. Muscle Injuries in Sports: A New Evidence-Informed and Expert Consensus-Based Classification with Clinical Application. *Sports Med* 2017;47:1241-1253.
- 18 Finch CF, Cook J. Categorising sports injuries in epidemiological studies: the subsequent injury categorisation (SIC) model to address multiple, recurrent and exacerbation of injuries. *Br J Sports Med* 2014;48:1276-1280.
- 19 Orchard J, Best TM, Verrall GM. Return to Play Following Muscle Strains. *Clin J Sports Med* 2005;15:436-441.
- 20 Toohey LA, Drew MK, Fortington LV, Finch CF, Cook JL. An Updated Subsequent Injury Categorisation Model (SIC-2.0): Data-Driven Categorisation of Subsequent Injuries in Sport. *Sports Med* 2018;48:2199-2210.
- 21 Cohen J. A power primer. *Psychol Bull* 1992;112:155-159.
- 22 Coutts AJ, Kempton T, Sullivan C, Bilsborough J, Cordy J, Rampinini E. Metabolic power and energetic costs of professional Australian Football match-play. *J Sci Med Sport* 2015;18:219-224.
- 23 Fukunaga T, Roy RR, Shellock FG, Hodgson JA, Day MK, Lee PL, et al. Physiological Cross-Sectional Area of Human Leg Muscles Based on Magnetic Resonance Imaging. *J Orthop Res* 1992;10:926-934.
- 24 Lieber RL, Friden, J. Functional and clinical significance of skeletal muscle architecture. *Muscle Nerve* 2000;23:1647-1666.
- 25 Lai A, Schache AG, Lin YC, Pandy MG. Tendon elastic strain energy in the human ankle plantar-flexors and its role with increased running speed. *J Exp Biol* 2014;217:3159-3168.
- 26 Hof AL, van Zandwijk JP, Bobbert MF. Mechanics of human triceps surae muscle in walking, running and jumping. *Acta Physiol Scand* 2002;174:17-30.
- 27 Maniar N, Schache AG, Cole MH, Opar DA. Lower-limb muscle function during sidestep cutting. *J Biomech* 2018;82:186-192.
- 28 Koulouris G, Ting, A. Y., Jhamb, A., Connell, D., Kavanagh, E. C. Magnetic Resonance Imaging Findings of Injuries to the Calf Muscle Complex. *Skeletal Radiol* 2007;36:921-927.

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- 29 Lai A, Lichtwark GA, Schache AG, et al. In vivo behaviour of the human soleus with increased running and walking speeds. *J Appl Physiol* 2015;118:1266-1275.
- 30 Lai AKM, Lichtwark GA, Schache AG, Pandy MG. Differences in in vivo muscle fascicle and tendinous tissue behaviour between the ankle plantarflexors during running. *Scand J Med Sci Sports* 2018;28:1828-1836.
- 31 Ishikawa M, Pakaslahti J, Komi PV. Medial gastrocnemius muscle behaviour during human running and walking. *Gait Posture* 2007;25:380-384.
- 32 Orchard JW, Alcott E., James T., Farhart P., Portus M., Waugh SR. Exact moment of a gastrocnemius muscle strain captured on video. *Br J Sports Med* 2002;36:222-223.
- 33 Campbell JT. Posterior calf injury. *Foot Ankle Clin N Am* 2009;14:761-771.
- 34 Dixon JB. Gastrocnemius vs. soleus strain: how to differentiate and deal with calf muscle injuries. *Curr Rev Musculoskelet Med* 2009;2:74-77.
- 35 Jacobs R, Bobbert MF, van Ingen Schenau GJ. Function of mono- and biarticular muscles in running. *Med Sci Sport Exerc* 1993;25:1163-1173.
- 36 Gollnick PD, Sjodin B, Karlsson J, Jansson E, Saltin B. Human Soleus Muscle: A Comparison of Fiber Composition and Enzyme Activities with Other Leg Muscles. *Pflugers Arch* 1974;348:247-255.
- 37 Edgerton VR, Smith, J. L., & Simpson, D.R. Muscle fibre type populations of human leg muscles. *Histochemical Journal* 1975;7:259-266.
- 38 Hodgson JA, Finni T, Lai AM, Edgerton VR, Sinha S. Influence of Structure on the Tissue Dynamics of the Human Soleus Muscle Observed in MRI Studies During Isometric Contractions. *J Morphol* 2006;267:584-601.
- 39 Bolsterlee B, Finni T, D'Souza A, Eguchi J, Clarke EC, Herbert RD. Three-dimensional architecture of the whole human soleus in vivo. *PeerJ* 2018;6:e4610.
- 40 Kinugasa R, Oda T, Komatsu T, Edgerton VR., Sinha S. Interaponeurosis shear strain modulates behaviour of the myotendinous junction of the human triceps surae. *Physiol Rep* 2013;1:1-14.
- 41 Hamilton B, Valle X, Rodas G, Til L, Pruna RP, Rincon JAG, et al. Classification and grading of muscle injuries: a narrative review. *Br J Sports Med* 2015;49:306-312.
- 42 Askling C, Saartok T, Thorstensson A. Type of acute hamstring strain affects flexibility, strength, and time to return to pre-injury level. *Br J Sports Med* 2006;40:40-44.
- 43 Askling CM, Tengvar M, Saartok T, Thorstensson A. Acute First-Time Hamstring Strains During Slow-Speed Stretching. *Am J Sports Med* 2007;35:1716-1724.

- 44 Bertelson ML, Hulme A, Peterson J, Brund RK, Sorensen H, Finch CF, et al. A framework for the etiology of running-related injuries. *Scand J Med Sci Sports* 2017;27:1170-1180.
- 45 Schache AG, Dorn TW, Williams GP, Brown NAT, Pandy MG. Lower-Limb Muscular Strategies for Increasing Running Speed. *J Orthop Sports Phys Ther* 2014;44:813-824.
- 46 Wangensteen A, Tol J, Witvrouw E, Van Linschoten R, Almus E, Hamilton B, et al. Hamstring Reinjuries Occur at the Same Location and Early After Return to Sport: A Descriptive Study of MRI-Confirmed Reinjuries. *Am J Sports Med* 2016;44:2112-2121.
- 47 Sanfilippo J, Silder A, Sherry MA, Tuite MJ, Heiderscheit BC. Hamstring Strength and Morphology Progression after Return to Sport from Injury. *Med Sci Sport Exerc* 2013;45:448-454.
- 48 Connell DA, Schneider-Kolsky ME, Hoving JL, Malara F, Buchbinder R, Koulouris G, et al. Longitudinal Study Comparing Sonographic and MRI Assessments of Acute and Healing Hamstring Injuries. *AJR Am J Roentgenol* 2004;183:975-984.
- 49 Jarvinen TAH, Jarvinen M, Kalimo H. Regeneration of injured skeletal muscle after the injury. *Muscles Ligaments Tendons J* 2013;3:337-345.
- 50 Orchard J, Best TM. The Management of Muscle Strain Injuries: An Early Return Versus the Risk of Recurrence. *Clin J Sport Med* 2002;12:3-5.
- 51 Bayer ML, Hoegberget-Kalisz M, Jensen MH, Olesen JL, Svensson RB, Couppe C, et al. Role of tissue perfusion, muscle strength recovery, and pain in rehabilitation after acute muscle strain injury: A randomized controlled trial comparing early and delayed rehabilitation. *Scand J Med Sci Sports* 2018;28:2579-2591.
- 52 Arden CL, Glasgow P, Schneiders A, Witvrouw E, Clarsen B, Cools A, et al. 2016 Consensus statement on return to sport from the First World Congress in Sports Physical Therapy, Bern. *Br J Sports Med* 2016;50:853-864.
- 53 Green B, Pizzari T. Calf muscle strain injuries in sport: A systematic review of risk factors for injury. *Br J Sports Med* 2017;51:1189-1194.

LEGEND FOR TABLES AND FIGURES

Table 1. The number of injuries that occurred in each season and the primary musculotendinous structure injured

CMSI= calf muscle strain injury, MRI= magnetic resonance imaging

Table 2. The characteristics of the injured players

CMSI= calf muscle strain injuries, Non-indig.= Non-indigenous player, Indig.=Indigenous player; Dom= dominant, Non-dom= Non-dominant, Fwd= forward line; Bck= back line; Mid= midfield; Ru= ruck; Ut= utility;
*statistically significant difference compared to index injuries (p<0.05)

Table 3. The time to reach recovery milestones following injury

CMSI= calf muscle strain injuries, SD= standard deviation, 95%CI= 95% confidence interval

*statistically significant difference compared to index injuries (p<0.05)

Figure 1. The cumulative incidence of re-injury

Note: the shaded region depicts +/- 1SD from the median number of days to return to play for index CMSI.

Figure 2. The stage of the competition season when CMSI occurred

CMSI= calf muscle strain injuries

Note: the shaded region depicts the competition period. The lined region depicts periods that were outside of the competition period.

Figure 3. The mechanism of injury for: (A) index injuries and re-injuries; and (B) soleus and gastrocnemius injuries

COD= change of direction

Figure 4. The timing of CMSI during matches for all match-related soleus and gastrocnemius injuries

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