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ORIGINAL RESEARCH

A Novel Quantitative Index for Objective MRI Grading of Gastrocnemius Muscle Strain

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ABSTRACT

This study presents a quantitative MRI-based method to improve the objectivity and diagnostic accuracy of grading calf muscle strains. Ninety-six patients with MRI-confirmed medial gastrocnemius injuries who underwent bilateral lower leg MRI between January 2018 and December 2023 were retrospectively analyzed. Injuries were graded using the Dai classification (Grades I–III). Axial T2-weighted SPAIR images were used to measure the medial gastrocnemius cross-sectional area (CSA) at the distal one-third between the knee joint and the musculotendinous junction. The Gastrocnemius Medial Head Ratio (GCM ratio) was calculated by dividing the CSA of the injured side by that of the uninjured side. Two experienced radiologists independently performed the measurements twice. Intra- and interobserver reliability were assessed using intraclass correlation coefficients (ICC) and Cohen's kappa. A one-way ANOVA with the Bonferroni correction was used for group comparisons. ROC analysis evaluated the diagnostic performance of the GCM ratio. The GCM ratio significantly differed among Grade I (1.03 ± 0.02), Grade II (1.18 ± 0.06), and Grade III (1.35 ± 0.05) injuries ($p < 0.001$). Ipsilateral CSA increased with injury severity, whereas contralateral CSA remained consistent. CSA measurements showed excellent intra- and interobserver reliability (ICC > 0.87), and lesion grading demonstrated substantial to almost perfect agreement (κ = 0.75–0.88). ROC analysis revealed strong diagnostic accuracy (AUC = 0.986 for Grade I vs. II; AUC = 1.000 for Grade II vs. III). The GCM ratio provides a reproducible and objective MRI marker to aid in grading gastrocnemius strains, offering excellent diagnostic performance and clinical applicability.

Keywords: Tennis leg. Gastrocnemius. MRI. Cross-sectional area. Muscle grading. quantitative imaging.

Gastroknemius Kas Yırtıklarının Objektif MRG Sınıflaması için Yeni Bir Kantitatif İndeks

ÖZET

Bu çalışmanın amacı, medial gastroknemius kasının yaralı ve sağlam taraflardaki kesitsel alan (KA) ölçümlerini karşılaştırarak baldır kası yaralanmalarının sınıflamasında nesnelliği ve tanısal doğruluğu artırmak üzere MRG tabanlı kantitatif bir yaklaşım geliştirmektir. Bu retrospektif çalışmaya, Ocak 2018 ile Aralık 2023 tarihleri arasında çift taraflı alt ekstremite MRG'si çekilmiş ve MRG ile baldır kası yırtığı doğrulanmış 96 hasta dahil edildi. Kas yaralanmaları Dai sınıflamasına göre (Grade I–III) sınıflandırıldı. Medial gastroknemius kasının KA ölçümleri, diz eklemi ile muskulo-tendinöz bileşke arasındaki distal üçte birlik seviyede elde edilen aksiyel T2-ağırlıklı SPAIR sekanslar kullanılarak yapıldı. Gastroknemius Medial Baş Oranı (GKM oranı), yaralı tarafın KA'sının sağlam tarafın KA'sına oranlanmasıyla hesaplandı. İki deneyimli radyolog ölçümleri birbirinden bağımsız ve iki kez gerçekleştirdi. İntra ve inter-observer güvenilirlik intraclass correlation coefficient (ICC) ve Cohen's kappa istatistikleri ile değerlendirildi. Gruplar arası karşılaştırmalarda Bonferroni düzeltmeli tek yönlü ANOVA testi kullanıldı. GKM oranının tanısal performansı ROC analizi ile değerlendirildi. GKM oranı Grade I (1,03 ± 0,02), Grade II (1,18 ± 0,06) ve Grade III (1,35 ± 0,05) arasında anlamlı fark gösterdi ($p < 0{,}001$). Yaralı taraftaki KA, yaralanma şiddetiyle birlikte artış gösterirken; sağlam taraf KA'sı gruplar arasında anlamlı fark göstermedi. KA ölçümlerinin inter- ve intra-observer güvenilirliği mükemmeldi (ICC > 0,87), lezyon derecelendirmesi ise anlamlı düzeyde tutarlıydı (κ = 0,75–0,88). ROC analizi, GKM oranı için yüksek tanısal doğruluk gösterdi (Grade I ile II için AUC = 0,986; Grade II ile III için AUC = 1,000). Gastroknemius kasının GKM oranına dayalı kantitatif MRG ölçümleri, yaralanma sınıflamasında yüksek tekrarlanabilirlik ve güçlü tanısal performans ile güvenilir ve objektif bir değerlendirme aracı sunmaktadır.

Anahtar Kelimeler: Tenisçi bacağı. Gastroknemius. MRG. Kesitsel alan. Kas sınıflaması. kantitatif görüntüleme.

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Tennis leg, a common calf muscle injury, typically refers to a partial rupture of the medial gastrocnemius at the level of the musculotendinous junction, often seen in recreational athletes.[1] It is characterized by a sudden onset of sharp pain in the calf, frequently described as a "snapping" sensation during activities involving acceleration or abrupt movements. Clinically, patients present with localized tenderness, swelling, and difficulty with weight-bearing or pushing off on the affected leg. [2,3] Diagnosis of tennis leg primarily relies on clinical history and physical examination, but imaging, particularly magnetic resonance imaging (MRI), plays a pivotal role in confirming the diagnosis, assessing the extent of the injury, and guiding treatment.[4,5] Treatment options range from conservative management, including rest and physiotherapy, to surgical intervention in more severe cases.[3] Accurate MRI grading of calf muscle injuries is not only critical for determining the appropriate treatment strategy, predicting prognosis, and estimating the timeline for return to sports, recreational, or daily activities, but also plays a key role in guiding clinical decisions following diagnosis, such as selecting conservative versus more prolonged treatment approaches, tailoring rehabilitation protocols, identifying patients at risk for delayed recovery or recurrence, and facilitating standardized follow-up by providing a reproducible and objective reference for radiological monitoring.[6] Thus, the classification system is particularly valuable after diagnosis, during treatment decision-making, and follow-up monitoring.

MRI-based grading of calf muscle injuries serves as a standard tool for radiologists and clinicians.[7] However, the current classification systems rely heavily on subjective evaluation, leading to variability in interpretations.[8,9] These methods often lack quantitative measures, challenging the standardization of assessments across radiologists or institutions.[9]

This study aimed to introduce a quantitative approach to refine MRI grading of calf muscle injuries by comparing the cross-sectional area (CSA) of the injured muscle to that of the contralateral, healthy side. We hypothesize that this side-to-side comparison can provide a more accurate and objective framework for classifying injury severity, ultimately enhancing clinical decision-making and improving prognostic predictions.

Material and Method

Patients and Study Design

This retrospective radiological study reviewed the institutional digital database to identify patients who underwent MRI for suspected tennis leg between January 2018 and December 2023. As clinical follow-up data were not required, only the availability and quality of imaging were considered. All MRIs were obtained at a public university-affiliated training and research hospital over a six-year period. One hundred one patients with MRI-confirmed calf muscle strain injury (CMSI) were initially identified. Five patients were excluded because their imaging was unilateral, which prevented a side-to-side comparison. The final study sample consisted of 96 patients with bilateral lower leg MRI examinations deemed adequate for radiological analysis. Clinical informed consent was not required, as this study was based solely on anonymized imaging data. Institutional review board approval was obtained from the Antalya Training and Research Hospital Clinical Research Ethics Committee (Approval date and issue: 2024/15-18). The study adhered to the ethical principles of the Declaration of Helsinki and followed the STROBE guidelines for observational studies.[10]

MR Imaging

All MRI examinations were performed using standardized bilateral lower leg imaging protocols on two different MRI systems: a 1.5 Tesla Achieva DS Advance and a 3.0 Tesla Ingenia unit (both by Philips Healthcare, Eindhoven, The Netherlands). Imaging was conducted with the patient in the supine position using a 16-channel Sense XL Torso coil, which allows for simultaneous coverage of both lower legs. Although MRI examinations for post-traumatic evaluation are commonly requested unilaterally in routine clinical practice based on symptom localization, at our institution, lower extremity MRIs are routinely acquired bilaterally. This institutional protocol is driven by technical considerations and coil configuration, enabling comprehensive visualization of both crura within the same field of view. The bilateral acquisition not only facilitates a more consistent and reproducible imaging workflow but also allows direct side-to-side comparisons, which served as the basis for the quantitative assessment employed in this study. The imaging protocol included axial and coronal T1-weighted turbo spin echo (TSE) and T2-weighted SPAIR sequences. All images were stored and reviewed on a PACS workstation (Sectra IDS7, Version 18.2, Sectra AB, Sweden), which operates on a client-server architecture.

MRI evaluation and measurements

The grading of muscle injuries was based on the classification proposed by Dai et al., which divides muscle injuries into three groups.[4] Grade 1 is characterized by edema with no architectural disruption or macroscopic tear. Grade II is characterized by partial muscle disruption with hematoma or local disruption of muscle architecture. Grade III is characterized by a complete muscle disruption with local hematoma covering the tear cavity or tendon detachment (Figure 1).

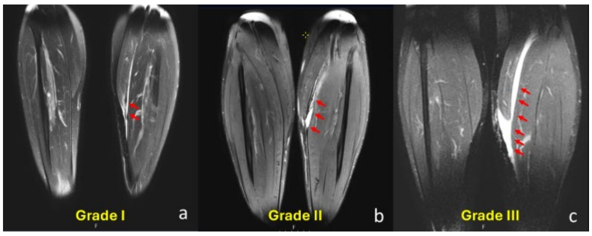

Figure 1.
Representative fat-suppressed T2-weighted coronal MRI images demonstrating the three grades of gastrocnemius muscle injury according to the Dai classification. (a) Grade I: mild intramuscular edema without visible structural disruption (red arrows). (b) Grade II: partial fiber disruption with focal hematoma and architectural distortion (red arrows). (c) Grade III: complete muscle rupture with fluid-filled tear cavity and retraction (red arrows).

Cross-sectional area measurements of the medial head of the gastrocnemius muscle were performed on both the injured and uninjured sides using axial T2-weighted SPAIR sequences. The axial level was selected at the distal one-third of the distance between the knee joint line and the musculotendinous junction. For each measurement, the fascial border of the muscle, characterized by a hypointense signal, was used as the anatomical reference. The measured area values were recorded in square millimeters (mm^2). The gastrocnemius medial head ratio (GMC ratio) was calculated by dividing the cross-sectional area of the injured side by that of the contralateral, uninjured side (Figure 2). The GMC ratio reflected the extent of edema and/or retraction on the injured side, with higher values indicating more pronounced muscle involvement and a higher grade.

Two radiologists with more than 10 years of experience in musculoskeletal imaging and MRI independently performed all evaluations. Each observer conducted the measurements twice, 15 days apart, while being blinded to their previous results and the measurements of the other observer. After completing all individual assessments, a final consensus on the injury grade was reached through a conjoint review meeting.

Statistical Analysis

Descriptive statistics were reported as means ± standard deviation (SD) for continuous variables and as frequencies and percentages for categorical variables. The normality of continuous variables was assessed using both the Kolmogorov–Smirnov and Shapiro–Wilk tests. One-way analysis of variance (ANOVA) was used to compare the Gastrocnemius Medial Head cross-sectional area (CSA) and GMC ratios across the three injury grades. Post-hoc pairwise comparisons were conducted using the Bonferroni correction to control for multiple testing. Receiver Operating Characteristic (ROC) curve analysis was used to evaluate the diagnostic performance of the GMC ratio in distinguishing between muscle injury grades. The area under the curve (AUC), optimal cut-off values, sensitivity, and specificity were calculated using Youden's Index. Intra-observer and inter-observer reliability were evaluated using Intraclass Correlation Coefficients (ICC) with 95% confidence intervals (CIs) for continuous variables, and Cohen's Kappa statistic with 95% CI for categorical variables. ICC values were interpreted as poor (<0.50), moderate (0.50–0.75), good (0.75–0.90), or excellent (>0.90). Kappa values were interpreted as poor (< 0.00), slight (0.00–0.20), fair (0.21–0.40), moderate (0.41–0.60), substantial (0.61–0.80), or almost perfect (0.81–1.00). The consensus-based injury grade was used for the final analysis, while the average of all cross-sectional area measurements was applied for ratio calculations. A p-value < 0.05 was considered statistically significant for all analyses.

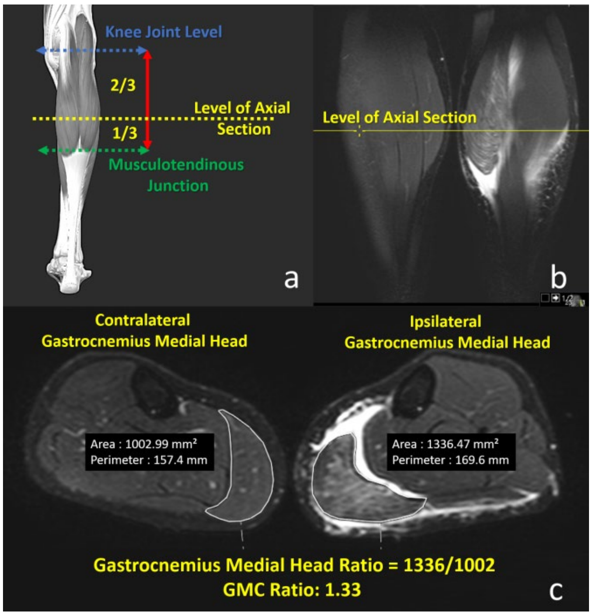

Figure 2.
Measurement of the medial head of the gastrocnemius muscle on axial T2-weighted SPAIR sequences. (a) Schematic illustration of the axial section level, positioned at the distal one-third of the distance between the knee joint and the musculotendinous junction. (b) Coronal MRI showing the selected axial plane. (c) Axial images of the contralateral (left) and ipsilateral (right) medial gastrocnemius heads. Cross-sectional area was measured using the fascial border as a reference. The Gastrocnemius Medial Head Ratio (GMC ratio) was calculated as the area of the injured side divided by the uninjured side.

Results

The final analysis included 96 patients. The mean age was 44.9 ± 10.4 years, with a range of 19 to 74 years. Of the participants, 70 (72.9%) were male, and 26 (27.1%) were female. Additional demographic characteristics are summarized in Table I.

Table I. Demographic characteristics of the patients.

Variables	Data
Number of patients	96
Age (years±SD, range)	44,9±10.4 (19-74)
Sex (n, %)	
Male	70 (72.9%)
Female	26 (27.1%)
Side	
Right	48 (50%)
Left	48 (50%)
Weight (kg±SD, range)	83.4±15.1 (55-125)
Height (cm±SD, range)	172.9±8.9 (150-192)
BMI (kg/m²±SD, range)	27.7±4.0 (20.2-38.5)

Abbreviations: n: number, SD: Standard Deviation, BMI: Body Mass Index.

Reliability analysis showed excellent intra-observer agreement for cross-sectional area measurements, with ICC values ranging from 0.963 to 0.976 for the gastrocnemius medial head and 0.945 to 0.984 for the contralateral side. The inter-observer ICC values also demonstrated high reliability, ranging from 0.869 to 0.937. The agreement for lesion grading was substantial to almost perfect, with intra-observer kappa values of 0.846 and 0.852, and inter-observer kappa values of 0.747 and 0.883 (Table II).

Table II. Results of reliability analysis.

Variables	Intra-observer Reliability, ICC or Kappa (95% CI)	
	A t_1 vs. A t_2	*B t_1 vs. B t_2*
GCM Ipsilateral	0.967 (0.951-0.978)	0.976 (0.964-0.984)
GCM Contralateral	0.963 (0.945-0.975)	0.971 (0.956-0.980)
Lesion Grade	0.846 (0.744-0.948) *	0.852 (0.746-0.958) *
	Interobserver Reliability, ICC or Kappa (95% CI)	
	A t_1 vs. B t_1	*A t_2 vs. B t_2*
GCM Ipsilateral	0.884 (0.831-0.921)	0.937 (0.907-0.958)
GCM Contralateral	0.869 (0.809-0.910)	0.923 (0.886-0.948)
Lesion Grade	0.747 (0.620-0.874) *	0.883 (0.721-0.945) *

*Kappa 95% CI, A represents the first observer, B represents the second observer.

Abbreviations: ICC: Interclass correlation analysis, CI: Confidence interval, GCM: Gastrocnemius medial head. t_1: First time, t_2: Second time

There was a statistically significant difference in the cross-sectional area of the ipsilateral gastrocnemius medial head with increasing injury severity (p = 0.001). No statistically significant difference was found in the contralateral muscle area across the grades (p = 0.324). The gastrocnemius medial head ratio (GCM ratio) also showed a significant difference among the groups, with increasing values corresponding to greater injury severity (p = 0.001). The mean GCM ratio was 1.03 ± 0.02 in Grade 1, 1.18 ± 0.06 in Grade 2, and 1.35 ± 0.05 in Grade 3 injuries (p = 0.001). Post-hoc analysis with the Bonferroni correction revealed that the ipsilateral area and the GCM ratio differed significantly between all grades (Table III and Figure 3).

Table III. Comparison of the Gastrocnemius Medial Head Ratio between grades.

Variable		Grade 1 *(n:17)*	Grade 2 *(n:63)*	Grade 3 *(n:16)*	p-value
GCM Ipsilateral	*(mm²±SD)*	1420.0±300.8	1732.9±362.3	2079.2±377.5	0.001[1]
	Range	796-1866	747-2485	1379-2732	
GCM Contralateral	*(mm²±SD)*	1369.7±303.3	1475.5±336.2	1534.2±284.0	0.324[1]
	Range	742-1851	625-2297	963-1933	
GCM Ratio	*(value ±SD)*	1.03±0.02	1.18±0.06	1.35±0.05	0.001[1]
	Range	1.01-1.10	1.06-1.29	1.3-1.49	

[1] ANOVA. Multiple post-hoc comparisons with the Bonferroni test revealed a significant difference between groups at the 0.005 level for GMC Ipsilateral and GMC Ratio.

Abbreviations: SD: Standard Deviation, GCM: Gastrocnemius medial head.

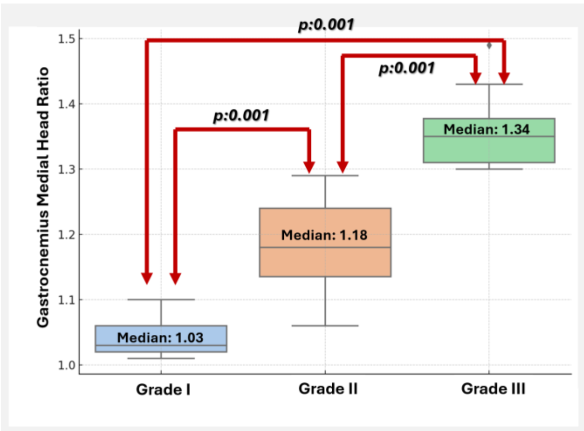

Figure 3.
Boxplot comparing the Gastrocnemius Medial Head Ratio (GMC ratio) across three muscle injury grades.

Receiver operating characteristic (ROC) curve analysis demonstrated excellent diagnostic performance of the GCM ratio (Figure 4). In distinguishing between Grade 1 and Grade 2 injuries, the area under the curve (AUC) was 0.986, with a best threshold of 1.09, yielding a sensitivity of 93.7% and a specificity of 94.1%. For the differentiation of Grade 2 from Grade 3, the AUC was 1.000, with a best threshold of 1.30 and perfect sensitivity and specificity (100%) (Figure 5).

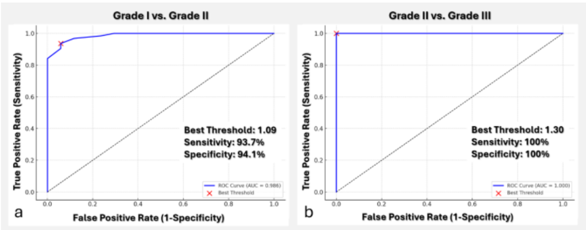

Figure 4.

Receiver Operating Characteristic (ROC) curves illustrating the diagnostic performance of the Gastrocnemius Medial Head Ratio (GMC ratio) for distinguishing between muscle injury grades. (a) ROC curve for Grade I vs. Grade II showing an AUC of 0.986 with a best threshold of 1.09, yielding a sensitivity of 93.7% and specificity of 94.1%. (b) ROC curve for Grade II vs. Grade III demonstrating perfect diagnostic performance with an AUC of 1.000, best threshold of 1.30, and 100% sensitivity and specificity.

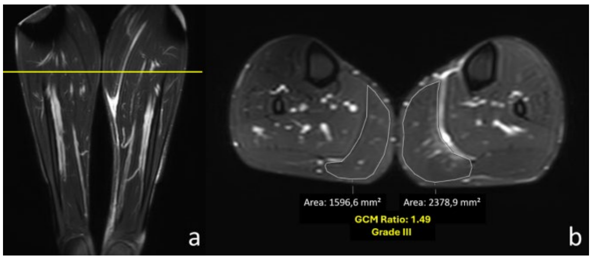

Figure 5.

MRI example of a patient with a Grade III calf muscle injury. (a) Coronal fat-suppressed T2-weighted image showing the level of axial section (yellow line) used for cross-sectional measurement. (b) Axial image at the corresponding level demonstrates medial gastrocnemius muscle measurements on the injured (right) and contralateral (left) sides. The calculated GCM ratio is 1.49, indicating significant edema and retraction consistent with a Grade III injury.

Discussion and Conclusion

This study demonstrates that quantitative analysis of the medial gastrocnemius muscle cross-sectional area (CSA) using MRI can significantly improve the objectivity and diagnostic accuracy of muscle injury grading. We found a strong correlation between ratio values and established injury severity grades by introducing the Gastrocnemius Medial Head Ratio (GCM ratio) as a measurable parameter. The GCM ratio increased consistently across Grades I to III, and ROC curve analysis revealed excellent discriminative performance, particularly between Grades II and III, where the diagnostic accuracy reached 100%. These findings suggest that supplementing conventional MRI-based grading with side-to-side CSA comparisons offers a reproducible and highly sensitive method for refining the assessment of calf muscle injuries.[11–13]

Numerous MRI-based classification systems have been developed to evaluate skeletal muscle injuries, particularly in athletes, ranging from simple clinical grading to anatomically detailed imaging models. The traditional Grade I–III system remains popular due to its simplicity; however, it lacks anatomical specificity and prognostic precision.[13] More advanced approaches, such as the modified Peetrons grading[14] and the British Athletics Muscle Injury Classification[15] (BAMIC), have attempted to incorporate MRI findings, focusing on the severity of structural disruption and the type of tissue involved. The Olympic Park classification, introduced by Prakash et al., [16] emphasized the involvement of connective tissue elements, such as the epimysium, aponeurosis, and tendon, and demonstrated a correlation with return-to-play duration. Additionally, anatomically complex schemes, such as the Chan classification[14] and the FC Barcelona and Munich consensus[17] models, offer detailed injury mapping but are often hindered by their complexity and reduced interobserver agreement.[9]

As highlighted by Hamilton et al.,[9] a common limitation among these systems is their heavy reliance on qualitative descriptors and expert-level anatomical interpretation, resulting in limited reproducibility and poor integration into routine radiological workflows. For instance, in the BAMIC system, categorizing a lesion as "myotendinous" versus "intramuscular" may vary depending on the radiologist's experience and anatomical familiarity.[17,18] Similarly, the Munich model's distinction between "functional" and "structural" injuries is based on subjective clinical assessment rather than reproducible imaging features. Although the Olympic Park classification incorporates MRI findings more directly, it still depends on the reader's ability to discern subtle disruptions in connective tissue structures—findings that may not be consistently visualized across all sequences. Moreover, most systems lack clearly defined, quantifiable thresholds, which reduces standardization and increases interobserver variability. These issues limit their practicality, particularly in time-constrained clinical settings that require rapid, consistent, and reproducible evaluation tools.

To address these shortcomings, the present study introduces the Gastrocnemius Medial Head Ratio (GCM ratio), a novel, quantitative, and objective index based on the comparison of the cross-sectional area of the medial gastrocnemius muscle between limbs.[16] This measurement can be easily derived from standard axial T2-weighted images without the need for post-processing, advanced segmentation tools, or deep anatomical knowledge, and it demonstrated excellent intra- and interobserver reliability. Unlike classifications that emphasize tissue type or site-specific disruption alone, the GCM ratio reflects the cumulative impact of edema, muscle fiber retraction, and structural damage elements that correlate with clinical severity and functional impairment. Thus, this method provides a reproducible and clinically applicable grading tool suitable for both initial diagnosis and longitudinal follow-up in sports medicine practice, effectively bridging the gap between complex descriptive systems and practical clinical utility.[19]

Furthermore, our findings highlight the diagnostic potential of the GCM ratio, with near-perfect discrimination between injury grades, as demonstrated by AUC values exceeding 0.98. This contrasts with prior studies, such as those validating the BAMIC[15] or Olympic Park systems,[16] where interrater variability and moderate prognostic correlations limited widespread clinical implementation. By integrating a continuous variable into the injury assessment process, our approach aligns with the literature's calls for more quantifiable, MRI-based parameters that support both grading and prognostic stratification.[6,20] Importantly, the GCM ratio does not require advanced software or high-resolution 3D reconstructions, making it feasible for use in standard radiology workflows. As such, this study provides a significant advancement in the objective evaluation of gastrocnemius muscle injuries and may serve as a foundation for future validation studies aimed at standardizing muscle injury classification and prognosis.

The primary strength of this study lies in the introduction of a novel, objective, and easily applicable MRI-based index—the Gastrocnemius Medial Head Ratio (GCM ratio)—for grading calf muscle injuries.[11,19] Unlike existing classification systems that rely predominantly on qualitative assessment or complex anatomical subtyping, the GCM ratio provides a reproducible, quantitative metric that can be integrated into routine clinical imaging protocols.[9] The high intra- and interobserver reliability observed in this study further supports its applicability in various radiological settings. Additionally, the use of bilateral MRIs enabled direct side-to-side comparison, enhancing the precision of CSA-based evaluations and reducing interindividual variability.[6]

However, the study has some limitations. First, its retrospective design may introduce selection bias, although strict imaging inclusion criteria were applied. Second, while the Dai classification was used as a reference standard for injury grading, it remains a descriptive system and lacks histopathological correlation.[15] Third, although the GCM ratio showed excellent diagnostic performance, this study did not include clinical outcome measures such as return-to-sport time or functional recovery, which would be essential for evaluating prognostic utility. Finally, the findings are based on a single-center cohort and may require external validation across broader populations and imaging platforms before generalizability can be confirmed.[12,21]

This study introduces the Gastrocnemius Medial Head Ratio (GCM ratio) as a reliable and objective MRI-based index for grading calf muscle injuries. By quantifying side-to-side differences in cross-sectional area, the GCM ratio enhances the precision and reproducibility of injury assessment beyond conventional qualitative systems. The strong correlation between ratio values and injury severity, along with excellent diagnostic performance, supports its potential as a practical adjunct to existing classification models. Future prospective studies linking this index to clinical outcomes such as recovery time and return-to-play are warranted to further validate its prognostic value and facilitate its integration into standardized muscle injury assessment protocols.

Researcher Contribution Statement:
Idea and design: K.K.K., N.K.; Data collection and processing: M.Y., M.B.E.; Analysis and interpretation of data: O.K., N.K.; Writing of significant parts of the article: K.K.K., M.Y., M.B.E.
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