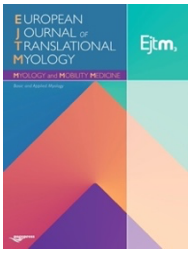
European Journal of Translational Myology



pISSN: 2037-7452 eISSN: 2037-7460

https://www.pagepressjournals.org/index.php/bam/index

Eur J Trans Myol 2024 [Online ahead of print]

To cite this Article:

Shi H, Jv L, Xu J, Qian X. **An in-depth study on the magnetic resonance imaging characteristics of tendon rupture in sports injuries and its correlation with patients' clinical symptoms.** *Eur J Trans Myol* doi: 10.4081/ejtm.2024.12424

An in-depth study on the magnetic resonance imaging characteristics of tendon rupture in sports injuries and its correlation with patients' clinical symptoms

Haihua Shi,[1] Lingjuan Jv,[2] Jungang Xu,[3] Xiangyu Qian[4]

[1]Department of Radiology, Hangzhou Shangcheng District People's Hospital, Hangzhou City, Zhejiang Province; [2]Department of Internal Medicine, Tongxiang Third People's Hospital, Jiaxing City, Zhejiang Province; [3]Department of Orthopedics, Hangzhou Shangcheng District People's Hospital, Hangzhou City, Zhejiang Province; [4]Department of Radiology, Tongxiang TCM Hospital, Jiaxing City, Zhejiang Province, China

Correspondence: Haihua Shi, Department of Radiology, Hangzhou Shangcheng District People's Hospital, 310021 Hangzhou City, Zhejiang Province, China.

E-mail: Txshh@126.com

Key words*:* Achilles tendon, quadriceps tendon, MRI, rupture, tear, injury.

Conflict of interest: the authors declare no potential conflict of interest, and all authors confirm accuracy.

Ethics approval: the study was approved by the Institutional Review Board of the Second Affiliated Hospital of Zhejiang University of Traditional Chinese Medicine (Zhejiang Xinhua Hospital). Informed consent was provided for the retrospective analysis of MR images of AT and QT ruptures. The data collected was exclusively used for research purposes and any personal identifiers were removed.

Informed consent: all patients participating in this study signed a written informed consent form for participating in this study.

Patient consent for publication: written informed consent was obtained from a legally authorized representative(s) for anonymized patient information to be published in this article.

Availability of data and materials: all data generated or analyzed during this study are included in this published article.

Lingjuan Jv

Orcid ID: 499487503@qq.com

E-mail: 0009-0003-2409-0549

Jungang Xu

Orcid ID: 0009-0004-1745-1470

E-mail: txshh112233@163.com

Xiangyu Qian

Orcid ID: 0009-0005-3543-9413

E-mail: hzshh112233@163.com

Abstract

Muscle injuries, such as Achilles and quadriceps tendon ruptures, pose a significant challenge in elite sports, accounting for more than 30% of all sports-related injuries. Our primary goal is to investigate the MR imaging characteristics of tendon rupture in sports injuries and their relationship with patients' clinical symptoms. In our retrospective study at Zhejiang University of Traditional Chinese Medicine's Second Affiliated Hospital (Zhejiang Xinhua Hospital), we compared the clinical presentation and MRI results of 106 patients with isolated AT and QT ruptures. In the AT, the enthesis was identified as a common site of bony avulsions (30.2%). In contrast, insertional ruptures were more common in the gastrocnemius heads (69.8% and 66.0%). The low frequency of mid-substance tears (13.2% to 20.8%) demonstrated the central tendon region's inherent tensile strength. The ruptured musculotendinous junctions affected the soleus (20.8%). In QT, bony avulsions play a minor role (5.1% to 11.3%). The patella was the primary site of tears (42.2% - 45.3%), with the Vastus intermedius favoring proximal tears (58.5%). Our examination of AT and QT ruptures across sub-components sheds light on their distinct patterns and the implications for clinical practice in terms of precise diagnosis, personalized treatment, and, ultimately, better patient outcomes for these debilitating injuries.

Introduction

Muscle injuries constitute a significant challenge in elite sports by accounting for more than 30% of sports-related injuries.[1-3] There is a significant amount of time lost to muscle injuries from weeks, months, and years.[4] Rupture of the Achilles tendon (AT) is the most common and devastating injury for athletes that requires surgical repair and recovery duration of 6 months to 1 year.[5] Aerial sports involving frequent and consistent landings and jumping such as gymnastics, dancing, and cheerleading have the greatest risk of AT injury. Similarly, ground-based sporting activities involving speed and footwork such as football, tennis, and long-distance running have a higher risk of AT injury.[6,7]

The Achilles tendon consists of three twisted sub-tendons with two originating from the medial and lateral tips of the gastrocnemius muscle and another one from the soleus muscle.[8,9] The anterior section of the Achilles tendon contains a sub-tendon from the tip of the gastrocnemius while the medial section is composed of the soleus sub-tendon. The posterior outline of the Achilles tendon contains a sub-tendon emerging from the medial tip of the gastrocnemius.[10] According to Szaro *et al.*,[11] the magnetic resonance imaging (MRI) of the normal AT on PD and T2 weighted sequences is usually low with the individual sub-tendons separated by high septae. The commonly visualized septae lie within the anterior section of the tendon situated between the sub-tendons of the soleus and the lateral tip of the gastrocnemius muscle.

The quadriceps tendon (QT) is situated at the muscular junction and connects the muscle group of the quadriceps. This muscle group consists of the rectus femoris, vastus lateralis, vastus medialis, and vastus intermedius muscles located at the anterior superior tip of the patella. The extensor mechanisms of the lower leg consist of the patellar bone, patellar tendon, and quadriceps tendon that allow withstanding of structural and biomechanical loads without rupture.[12,13] QT rupture are caused by extreme eccentric loading within the knee extensor networks which is a result of the spontaneous and robust contractions of the quadriceps from jumping and landing sporting activities. The rupture of the quadriceps tendon is caused by spontaneous changes in directions while running or attempts to regain balance in avoiding falls.

Yang et al.,[14] suggested that the common symptoms of tendon rupture are caused by a feeling of being kicked in the calf, pain and severe swelling near the heels, inability to stand on the toes in the injured leg, and bending the foot downwards. Moreover, a snapping sound often occurs when the injury happens. The risk of AT increases with an increase in age (30 to 40 years), sex (men have a 5 times higher chance of AT injury compared to women), participation in recreational sports involving running, jumping, spontaneous starts, and stops activities such as tennis, basketball, and soccer.

Recent studies on new level I evidence have suggested that there are no differences in the rates of re-rupture of tendons. There is a 10% to 40% chance of re-rupture reported in previous literature with cases of non-operative management occurring at 1% to 2% post-surgery. According to Lantto *et al*.,[16] a randomized controlled trial of 6o patients recruited from 2009 to

2013 with 18 months of follow-up showed high levels of similarity in Achilles tendon performance scores between control and intervention groups with a slightly increased calf muscle strength that favored the operative group at 10 to 18% difference at 18 months of follow-up. Moreover, there were health and increased quality of life scores in the aspects of physical functioning and body pains in the operative group. In wound healing complications, there was a 5 to 10% risk after surgical operations. The risk factors for post-surgical wound complications included smoking which is a common and most important risk factor preceded by female gender, use of steroids, and individuals who chose open surgical techniques compared to percutaneous procedures. Lastly, sural nerve injuries increased in patients who underwent percutaneous procedures compared to open surgical techniques.

The rationale of our study is to fill the missing gap in the discrepancies reported in the sites of AT and quadriceps tears based on the location (at the bone insertion on the patella compared to the intra-tendinous) and the extent of tear (superficial tears compared to deeper layers). Previous studies have utilized a smaller number of cases that were mostly cited in reviews and systematic analyses which have purported the existing hypotheses as the findings. For example, a study by Zeiss *et al.*,[15] analyzed all the anatomical layers associated with the quadriceps tendon and it was inconclusive on which of the five abnormal quadriceps tendons tended to have the highest degree of rupture and associated patient symptoms. Therefore, the main objective of our study is to carry out an in-depth study on the MR imaging characteristics of tendon rupture in sports injuries and its correlation with patients' clinical symptoms.

Materials and Methods

Study design

A retrospective observational study was conducted at the Second Affiliated Hospital of Zhejiang University of Traditional Chinese Medicine (Zhejiang Xinhua Hospital). The study compared the clinical presentation and MRI results of 106 patients with isolated AT ruptures and quadriceps tendon ruptures.

Patients and medical records

All the patients and medical records were reviewed for both AT and QT rupture injuries. In AT, the medical records were examined for various treatment approaches (conservative or surgical treatment), surgical details used and the surgical findings (the extent of tear, partial and complete tears), comorbidities (presence or absence of existing conditions such as vascular disorders, collagen disorders, gout, and type 1/2 diabetes. The mechanism of trauma was also examined (low-energy versus high-energy). In QT rupture injuries were examined with a focus on the patellar tendon.

Ethics

The study was approved by the Institutional Review Board of the Second Affiliated Hospital of Zhejiang University of Traditional Chinese Medicine (Zhejiang Xinhua Hospital). Informed consent was provided for the retrospective analysis of MR images of AT and QT ruptures. The data collected was exclusively used for research purposes and any personal identifiers were removed.

Eligibility criteria

The inclusion criteria involved patients who were diagnosed with isolated AT or QT ruptures between December 2021 and December 2023 with confirmed clinical examination by MRI. The diagnosis for AT or QT rupture was based on physical examination findings from positive Thompson's test and the presence of a palpable gap for AT while in QT, positive test for patellar tilt and patellar apprehension test. High-resolution MRI consisting of fat-suppressed sequences demonstrating complete or partial tear with retraction for AT were included. Also, in QT, tear location (proximal, distal, or patellar tendon) was included with bone fragments.

The exclusion criteria involved patients with pre-existing tendon pathology and a history of prior surgical or trauma affecting the AT or QT. Also, incomplete medical records and missing MRI images were excluded with cases of concomitant injuries to the knee or ankle.

MRI imaging and analysis of images

At the Second Affiliated Hospital of Zhejiang University of Traditional Chinese Medicine (Zhejiang Xinhua Hospital) MRI images were obtained in single hospital systems from two scanners (General Electric Scanners and Phillips Medical Systems) at settings of either 1.5T or 3.0T. The basic MRI protocol was composed of the sagittal proton-density (PD) fat-saturated images, sagittal PD non-fat saturated images, coronal PD fat-saturated images, axial T1 non-fat-saturated images, and axial T2 non-fat-saturated images. The analysis of images involved a randomized process carried out by two independent and trained musculoskeletal radiologists. The readers were blinded to the medical history and treatment of patients and their findings.

In MR imaging, tear characteristics for the QT involved the rectus femoris, vastus medialis, vastus lateralis, and vastus intermedius. Tendon quality was assessed based on normal, tendinosis, complete tear, or partial tear while the location of the tear was assessed based on bone avulsion, myotendinous junction, proximal to bone insertion, and at the bone insertion. The evaluation of tendinosis was based on the increase in the intensity of signals at the tendon or thickening of the tendon while partial tear was evaluated based on the partial disruptions of the tendon while the rest of the remaining sections were still intact and unaltered. All three imaging planes were adopted for increased accuracy. Analysis of conjoined vastus medialis and vastus lateralis tendons were assessed independently based on their lengths while the characterization of the tear was preceded by measuring the length of the remaining tendon stump and the retraction length of each tendon.

Radiographs were used in examining the presence or absence of bony avulsion fragments on the knees. Lateral radiographs were utilized in obtaining measurements and the distance of the fragment to the patella. The number of fragments was recorded as well as the largest avulsed fragment. Lastly, the enthesophytes were also recorded accompanied.

Data analysis

Statistical analyses were performed in GraphPad Prism version 9.5.1 and MS Excel at a $p < .05$. Descriptive statistics were presented as mean, standard deviations, range, and percentages. MRI features for both Achilles tendon (AT) and quadriceps tendon (QT) ruptures were examined. Inter-observer reliability analysis was performed using Cohen's Kappa and Wilcoxon-signed-rank test to quantify the agreement between the radiologists' interpretations.

Results

Clinical presentation and demographics

The study analyzed data from 106 patients diagnosed with either Achilles tendon (AT) or quadriceps tendon (QT) ruptures. The average age for the AT group (n=53) was 35.8 years (SD ± 9.2), with a male-to-female ratio of 42:11. Their average symptom severity score was 8.2 (SD ± 1.4), and their average functional limitations score was 14.3 (SD ± 2.1). The QT group (n=53) had a slightly younger average age of 32.1 years (SD ± 8.6), with a male-to-female ratio of 38:15. Compared to the AT group, their average symptom severity score was slightly lower at 7.5 (SD ± 1.8), and their average functional limitations score was also slightly lower at 13.1 (SD ± 2.5).

Treatment interventions

In the AT group (n=53), a conservative approach was chosen for 20% of the patients, while 80% underwent surgical repair. Among those who underwent surgery, percutaneous suture repair was the most common technique (60%). For the QT group (n=53), a slightly lower proportion of patients (30%) opted for conservative treatment compared to the AT group. However, the majority (70%) still received surgical intervention.

MRI findings and analyses

In Table 1, normal tendon morphology was identified in 10.4% of rectus femoris cases, 3.8% of vastus medialis cases, 13.2% of vastus lateralis cases, and 22.6% of vastus intermedius cases. Tendinosis was present in 9.4% of rectus femoris cases, 13.2% of vastus medialis cases, 11.3% of vastus lateralis cases, and 9.4% of vastus intermedius cases. Partial tears were observed in 22.6% of rectus femoris cases, 23.1% of vastus medialis cases, 30.2% of vastus lateralis cases, and 41.5% of vastus intermedius cases. Complete tears were observed in 57.6% of rectus femoris cases, 59.9% of vastus medialis cases, 45.3% of vastus lateralis cases, and 26.5% of vastus intermedius cases. Inter-reader agreement indicated good to excellent consistency between the assessments of the two radiologists for all quadriceps femoris muscles. Kappa values were 0.808 for rectus femoris, 0.761 for vastus medialis, 0.787 for vastus lateralis, and 0.687 for vastus intermedius.

In Table 2, Analysis of quadriceps femoris tendon quality about patellar avulsion revealed distinct patterns. Compared to cases without avulsion, rectus femoris, vastus medialis, and vastus lateralis tendons in avulsion cases exhibited significantly lower mean quality scores ($p < 0.05$). Notably, no significant difference in tendon quality was observed between avulsion and non-avulsion cases for the vastus intermedius muscle (see Figure 1).

In Table 3, bony avulsions represented a small proportion of tears in all muscles, ranging from 5.1% in the rectus femoris to 11.3% in the vastus medialis. The majority of tears occurred directly at the patella, accounting for 42.2%-45.3% across muscles. Notably, vastus intermedius displayed a higher propensity for tears proximal to the patella (58.5%) compared to other muscles (39.6%-50.6%) (See Figure 3C & D). Myotendinous junction tears were scarce, ranging from 1.9% to 3.8% across muscles (See Figure 3E). In Figure 2, most of the tendons tore at the bone insertion point or the proximal to the patella (see Figure 3A, B). Inter-reader agreement remained good for all muscles despite the adjusted data ($\kappa = 0.611$-0.675).

In Table 4, within the gastrocnemius heads tendons exhibited normal morphology (8.0% in the lateral head and 10.0% in the medial head). Tendinosis was present in 12% of both heads. Notably, both gastrocnemius heads displayed a higher prevalence of partial tear cases compared to complete tears (18.1% vs. 14.9% for the lateral head and 16.0% vs. 15.9% for the medial head). The Soleus presented a slightly different pattern, with a somewhat higher proportion of

normal tendons (13.0%) compared to the gastrocnemius heads. Tendinosis was less frequent in the Soleus (9.0%) compared to both gastrocnemius heads. Partial and complete tears in the Soleus were roughly equal in prevalence (15.1% and 15.9%, respectively). Inter-reader agreement, measured using Cohen's kappa coefficient, remained good for all sub-components (κ = 0.698-0.765).

In Table 5, bony avulsion was most prevalent in the enthesis (30.2%), highlighting its vulnerability due to direct attachment and high stress during plantarflexion. The gastrocnemius heads showcased a lower risk of bony avulsion (5.7% in the lateral head and 4.7% in the medial head). Mid-substance ruptures were relatively infrequent in all sub-components. The gastrocnemius heads displayed slightly higher proportions compared to Soleus (13.2% and 14.9% vs. 20.8%).

The majority of ruptures occurred at the muscle-tendon junction (insertional ruptures). Both gastrocnemius heads exhibited similar high percentages (69.8% in the lateral head and 66.0% in the medial head), due to anatomical placement. Soleus presented a slightly lower proportion of insertional ruptures (56.6%). Musculotendinous junction ruptures were the least frequent across all sub-components. Soleus demonstrated the highest percentage (20.8%), potentially due to its larger muscle volume and higher force demands at the muscle-tendon interface.

Correlations in MR imaging

In QT, the presence of bony avulsions showed that the vastus medialis and vastus lateralis tendon consistently and frequently tore at the bone insertion ($p < 0.01$) while the other sections showed no common sites for tear (see Figure 1). The presence of tendon stumps at the tear gap was found to be between 0.8 cm to 5.1 cm with a mean of 1.9 cm in the rectus femoris ($p = 0.002$), in vastus medialis the average length was 1.6 cm with a range of 0.3 to 3.9 cm, in vastus lateralis the average length was 1.5 cm with a range of 0.5 to 5 cm; and in the vastus intermedius, the average length was 1.6 cm with a range of 0.4 to 3.6 cm ($p = 0.034$).

The retraction length in the torn QT layers was between 0.6 cm to 6.1 cm with an average of 3 cm for the rectus femoris ($p = 0.067$), 2.8 cm for vastus medialis, and vastus lateralis while

vastus intermedius had an average length of 2.5 cm. All the differences in retraction length were not statistically significant ($p > 0.05$).

In the analysis, 80 cases underwent surgical treatment with 60 cases reported to have received transpatellar bone tunnel tendon fixation (see Figure 2A and 2B) with a single case reported to receive end-to-end tendon repair treatment. Patients who underwent surgical treatment reported complete and total tears of at least two or more layers of the QT. 10 cases were showing the rupture of two tendons, 20 cases of three tendons, and 24 cases of all components.

One patient was found with type 1 diabetes while 26 patients were found with type 2 diabetes. 15 patients were diagnosed with gout while 3 patients had collagen disorders (Sjogren's syndrome). There were 20 patients with vascular disorders consisting of peripheral vascular diseases, rheumatoid arthritis, Raynaud's disease, and venous insufficiency. 80 cases were found with low-energy trauma while 26 cases were found to have high-energy trauma.

There were 26 cases who were subjected to conservative treatment techniques such as T-scope braces, pain-alleviating drugs, and physical therapy. Twelve cases recorded partial tendon tears with one or several layers of tendons undergoing conservative treatment. The rest of the 14 cases were subdivided into those individuals who reported rupture in either one, two, three, or four sub-tendons. Patients subjected to conservative treatment were evaluated based on the clinical function of the knee and leg, co-morbidities, and benefit calculations based on the risk of surgical operations.

Discussion

The results suggest that while both groups experienced significant symptoms and limitations due to their tendon ruptures, the AT group seemed to suffer slightly more in terms of both symptom severity and functional limitations. Furthermore, the findings suggest that surgical repair is the more common management option for both AT and QT ruptures, although a small portion of patients in each group benefitted from conservative treatment. Additionally, the specific surgical techniques chosen varied slightly between the two groups, potentially reflecting differences in the nature and location of the tears. We found that patellar avulsion significantly impacts the

quality of the rectus femoris, vastus medialis, and vastus lateralis tendons, potentially influencing their biomechanical function and recovery potential.

Our findings align with previous studies[17,18] in suggesting that rupture of the QT is common in sporting activities with an incidence of 1.37 for every 100,000 persons per year. Clinical diagnosis of QT involves MRI and radiographs to reveal bony avulsions with additional cases requiring ultrasound. Our significant discovery was that the superficial and middle layers of the QT had a higher frequency of rupture compared to the deeper layers. The frequency of rupture was high in proximity to the patella with bony avulsions occurring in the higher levels of tear within the rectus femoris, vastus medialis, and vastus lateralis without affecting the vastus intermedius. These findings were consistent with Falkowski *et al.*[19] who suggested that in adult rabbits, 50% of the QT fibres must be compromised for a complete tear to occur, although, rupture is possible even under minimal loads within regions of weakness such as the osseotendinous junction,[22] and the hypovascularized zones.[20] Therefore, alterations in the vascular system were a risk factor for the degeneration and rupture of AT and QT.

Yepes *et al.*[20] postulated that in human beings within the hypovascularized zone situated 2 cm above the patella is a significant weak point that is prone to rupture and tear. Therefore, this zone constitutes a greater percentage of the ruptures compared to the osseotendinous junction. In comparison to our study, the distribution of rupture between these two locations varied significantly with 85% of rupture reported in the hypovascularized zone while 94% reported in the osseotendinous junction. Also, we reported a case where rupture was experienced at the myotendinous junction. The AT is encapsulated by paratenon and is usually not visible in an MRI analysis. The paratenon is composed of 40% elements of plantaris tendon and it is vascularized forming a significant part of the healing process of AT injury.[21-23] In a microscopy analysis, the paratenon forms a component of the AT fibres as an endotenon in which the nerves, blood vessels and tenocytes are situated.[24] The enthesis of AT refers to a complex interconnection of various structures between AT and calcaneus such as the sesamoid cartilage, fibrocartilage (forming the anterior section of the tendon), periosteal fibrocartilage (encapsulating the calcaneus), retrocalcaneal bursa and sections of the Kager's fat pad.[25-27]

The rapture of the QT is a common sports injury to the extensor mechanisms preceded by fractures of the patellar as a result of indirect-low energy traumatic experiences.[28] High hypovascularized anatomical regions situated within the tendons could be exposed to rupture.[20] Therefore, the accurate clinical diagnosis required customized treatment decisions to eliminate risks of contraction of quadriceps tendons associated with fibrosis and lost elasticity of muscle fibers.[18] The precise clinical features of QT tear are essential in determining the surgical plan for a patient. The prevalence of mid-substance tears is due to the sufficient proximal and distal remnants of tendon stumps which require a primary end-to-end repair using Krackow techniques at both ends of the tendon.[29,30] Moreover, tears at the osseotendinous junction or those with inadequate stumps are not capable of undergoing end-to-end repair; hence, a shift to the transpatellar bone tunnel technique in fixing the tendons.

In our study, 60 cases were subjected to transpatellar bone tunnel technique in fixing tendons with few cases receiving direct end-to-end tendon repair. Therefore, there is a positive correlation with the number of rupture cases at the proximal and myotendinous junction. Thus, the significant aspect during surgery is independent of whether the tendon rupture occurs directly at the bone or it has a residual stump; however, it depends on the quality of the resulting tendon stump. Ruptures closer to the patella have insufficient tendon stump size and low quality to permit end-to-end repair and therefore, a favourable shift to transpatellar bone tunnel tendon fixing technique.

In the distal section of the rectus femoris, there are three layers; the superficial layer formed by the rectus femoris, a middle layer formed by the vastus medialis and vastus lateralis, and the deeper layer consisting of the vastus intermedius.[15] The muscle fibers of the distal quadriceps femoris tendon combine with the tendinous sections lying about 3 cm in the proximal position to the patella. The superficial layer of the rectus femoris protrudes distally over the patella to the patellar tendon. The advancement in imaging technology such as radiography and MRI have led to consistent and accurate evaluation and analysis of clinical quadriceps that are at high risk of fracture and tear.[23,25] In our study, bony avulsions in the Rectus Femoris, Vastus Medialis, and Vastus Lateralis muscles were linked to more severe tears compared to the Vastus Intermedius ($p=0.020$-0.043). This emphasizes the need for cautious interpretation of radiographs in suspected patellar avulsions, as even with classic symptoms, up to half of cases have been

misdiagnosed in emergency departments.[31,32] Radiographs are capable of revealing not only suprapatellar enthesophytes but also patellar bone avulsions, indicating tendon rupture.[33] In cases of complete rupture, radiographs may show additional signs, such as abnormal patellar position due to an unopposed pull from the patellar tendon distally. Follow-up magnetic resonance (MR) imaging can distinguish between complete or partial quadriceps tendon tears and provide further information about the intra-articular state of the knee. However, identifying small bone avulsions on MR images may pose a challenge.[33]

Analysis of the Achilles tendon (AT) quality in rupture cases revealed distinct patterns across sub-components. The enthesis exhibited the highest frequency of complete tears (27.2%). This finding highlights the enthesis's vulnerability to ruptures due to its biomechanical function and high stress during plantarflexion. Interestingly, the percentage of tendons with normal morphology and tendinosis at the enthesis was similar (6.5% and 6.0%, respectively), suggesting that early-stage degenerative changes might not be as prevalent in this sub-component as in others. AT ruptures manifest differently depending on their location.[34,35] Bony avulsions at the enthesis trigger sudden, severe pain and a palpable gap, while mid-substance tears cause dull aching and calf weakness. Insertional ruptures, dominant in the gastrocnemius, bring intense “calf tear” pain and gait limitations, while musculotendinous junction tears, mainly in the Soleus, present with mild pulling sensations and subtle ankle instability. Understanding these location-specific symptoms allows for more accurate diagnosis and targeted treatment, speeding up recovery from this debilitating injury.

Understanding the specific sub-component of AT involved in the rupture allows for a more informed prediction of patient symptoms. For instance, sudden severe pain and a palpable gap at the heel point towards a bony avulsion, while weakness and limited calf muscle contraction suggest a mid-substance rupture. Insertional ruptures typically present with intense pain at the muscle-tendon junction and inability to plantarflex, whereas musculotendinous junction ruptures exhibit milder symptoms like pulling sensation and subtle gait abnormalities.

Conclusions

Our comprehensive examination of AT and QT ruptures, dissecting their sub-components, reveals intricate biomechanical patterns and clinical implications. The interplay between location and clinical presentation enhances the significance of our investigation. Each sub-component manifests distinctive symptoms – bony avulsions at the enthesis with sudden pain and palpable gaps, mid-substance tears with dull aches and calf weakness, gastrocnemius insertional ruptures with an unmistakable "calf tear" and gait limitations, and subtle Soleus musculotendinous junction ruptures with pulling sensations and ankle instability. Recognizing these relationships empowers clinicians to diagnose accurately and tailor precise treatment strategies for AT and QT.

References

1. Junge A, Engebretsen L, Mountjoy ML, et al. Sports injuries during the Summer Olympic Games 2008. Am J Sports Med 2009;37:2165-72.
2. Darrow CJ, Collins CL, Yard EE, Comstock RD. Epidemiology of severe injuries among United States high school athletes: 2005-2007. Am J Sports Med 2009;37:1798-805.
3. Ekstrand J, Hagglund M, Walden M. Epidemiology of muscle injuries in professional football (soccer) Am J Sports Med 2011;39:1226-32.
4. Ekstrand J, Healy JC, Walden M, et al. Hamstring muscle injuries in professional football: the correlation of MRI findings with return to play. Br J Sports Med 2012;46:112-117.
5. DeLee JC, Drez D, Miller MD. Achilles tendon injuries. In: Orthopaedic Sports Medicine: Principles and Practice. 3rd ed. Philadelphia, PA: Saunders Elsevier; 2010:2182-2205
6. Wertz J, Galli M, Borchers JR. Achilles tendon rupture: risk assessment for aerial and ground athletes. Sports Health 2013;5:407-9.
7. Gies N. Current Perspectives around Core Stability Training in the Sports Performance Domain (Doctoral dissertation, University of Central Lancashire).

8. 8. Szaro P, Witkowski G, Śmigielski R, et al. Fascicles of the adult human Achilles tendon-an anatomical study. Annals of Anatomy-Anatomischer Anzeiger 2009;191:586-93.
9. Pękala PA, Henry BM, Ochała A, et al. The twisted structure of the Achilles tendon unraveled: A detailed quantitative and qualitative anatomical investigation. Scand J Med Sci Sports 2017;27:1705-15.
10. Szaro P, Cifuentes Ramirez W, Borkmann S, et al. Distribution of the subtendons in the midportion of the Achilles tendon revealed in vivo on MRI. Sci Rep 2020;10:16348.
11. Szaro P, Nilsson-Helander K, Carmont M. MRI of the Achilles tendon-a comprehensive pictorial review. Part one. Eur J Radiol Open 2021;8:100342.
12. Barge-Caballero G, López-Bargiela P, Pombo-Otero J, Pardo-Martínez P. Quadriceps tendon rupture in wild-type transthyretin amyloidosis (ATTRwt). Eur Heart J 2019;40:1307.
13. Wu W, Wang C, Ruan J, et al. Simultaneous spontaneous bilateral quadriceps tendon rupture with secondary hyperparathyroidism in a patient receiving hemodialysis: A case report. Medicine (Baltimore) 2019;98:e14809.
14. Yang X, Meng H, Quan Q, et al. Management of acute Achilles tendon ruptures: a review. Bone Joint Res 2018;7:561-9.
15. Zeiss J, Saddemi SR, Ebraheim NA. MR imaging of the quadriceps tendon: normal layered configuration and its importance in cases of tendon rupture. AJR. Am J Roentgenol 1992;159:1031-4.
16. Lantto I, Heikkinen J, Flinkkila T, et al. A prospective randomized trial comparing surgical and nonsurgical treatments of acute Achilles tendon ruptures. Am J Sports Med 2016;44:2406-14.
17. Ponkilainen V, Kuitunen I, Liukkonen R, et al. The incidence of musculoskeletal injuries: a systematic review and meta-analysis. Bone Joint Res 2022;11:814-25.
18. Dettmer SM, Schweigkofler U, Hoffmann R. Treatment of acute and chronic ruptures of the extensor mechanism of the knee joints. Zeitschrift fur Orthopadie und Unfallchirurgie 2018;156:593-607.
19. Falkowski AL, Jacobson JA, Hirschmann MT, Kalia V. MR imaging of the quadriceps femoris tendon: distal tear characterization and clinical significance of rupture types. Eur Radiol 2021;31:7674-83.

20. Yepes H, Tang M, Morris SF, Stanish WD. Relationship between hypovascular zones and patterns of ruptures of the quadriceps tendon. JBJS 2008;90:2135-41.
21. Olewnik Ł, Wysiadecki G, Podgórski M, et al. The plantaris muscle tendon and its relationship with the Achilles tendinopathy. BioMed Res Int 2018;2018.
22. Olewnik Ł, Wysiadecki G, Polguj M, Topol M. Anatomic study suggests that the morphology of the plantaris tendon may be related to Achilles tendonitis. Surgical Radiol Anat 2017;39:69-75.
23. Müller SA, Evans CH, Heisterbach PE, Majewski M. The role of the paratenon in Achilles tendon healing: a study in rats. Am J Sports Med 2018;46:1214-9.
24. Sharma P, Maffulli N. Biology of tendon injury: healing, modeling and remodeling. J Musculoskel Neuronal Interact 2006;6:181.
25. Mathew AJ, Østergaard M. Magnetic resonance imaging of enthesitis in spondyloarthritis, including psoriatic arthritis-status and recent advances. Front Med 2020;7:296.
26. Benjamin M, McGonagle D. The enthesis organ concept and its relevance to the spondyloarthropathies. Adv Exp Med Biol 2009;649:57-70.
27. McGonagle D, Lories RJ, Tan AL, Benjamin M. The concept of a "synovio-entheseal complex" and its implications for understanding joint inflammation and damage in psoriatic arthritis and beyond. Arthritis Rheumatism 2007;56:2482-91.
28. McKinney B, Cherney S, Penna J. Intra-articular knee injuries in patients with knee extensor mechanism ruptures. Knee Surg Sports Traumatol Arthrosc 2008;16:633-8.
29. Hantes ME, Mathews R, Raoulis V, et al. Better knee function after surgical repair of acute quadriceps tendon rupture in comparison to acute patellar tendon rupture. Orthopaed Traumatol Surg Res 2019;105:119-23.
30. Omer MA, Malik SS, Malik A, et al. Diagnostic accuracy of ultrasound in detecting meniscal tears taking magnetic resonance imaging as gold standard. Biol Clinical Sci Res J 2020;2020:40.
31. Zribi W, Zribi M, Guidara AR, et al. Spontaneous and simultaneous complete bilateral rupture of the quadriceps tendon in a patient receiving hemodialysis: A case report and literature review. World J Orthoped 2018;9:180.

32. Neubauer T, Wagner M, Potschka T, Riedl M. Bilateral, simultaneous rupture of the quadriceps tendon: a diagnostic pitfall? Report of three cases and meta-analysis of the literature. Knee Surg Sports Traumatol Arthrosc 2007;15:43-53.
33. Pengas IP, Assiotis A, Khan W, Spalding T. Adult native knee extensor mechanism ruptures. Injury 2016;47:2065-70.
34. Lemme NJ, Li NY, DeFroda SF, Kleiner J, Owens BD. Epidemiology of Achilles tendon ruptures in the United States: athletic and nonathletic injuries from 2012 to 2016. Orthopaed J Sports Med 2018;6:2325967118808238.
35. Nicholson G, Walker J, Dawson Z, Bissas A, Harris N. Morphological and functional outcomes of operatively treated Achilles tendon ruptures. Physician Sportsmed 2020;48:290-7.

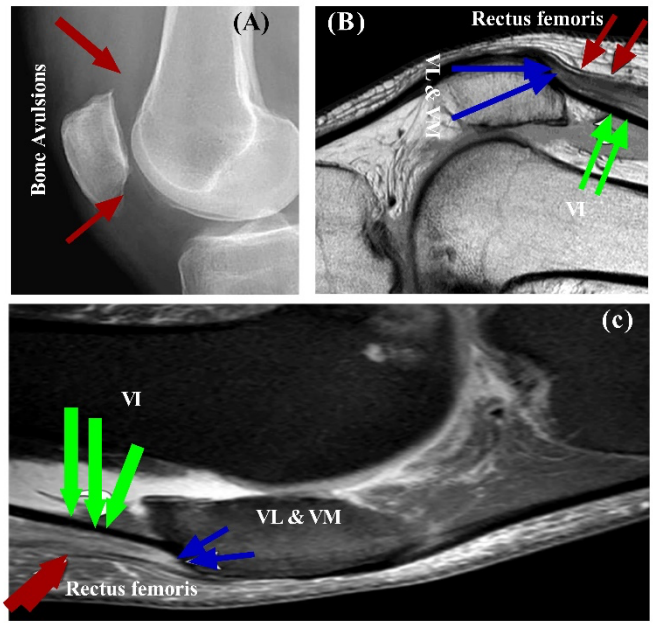


Figure 1. A case study of a conservative treatment of a 35-year-old male athlete with QT tear and signs of bone avulsion in section A, while section B shows A sagittal medial-weighted MR image and section C shows a sagittal MR image without fat suppression. The rectus femoris (red

arrows), vastus lateralis, and vastus medialis (blue arrows) are completely torn while the vastus intermedius is in a normal state (green arrows).

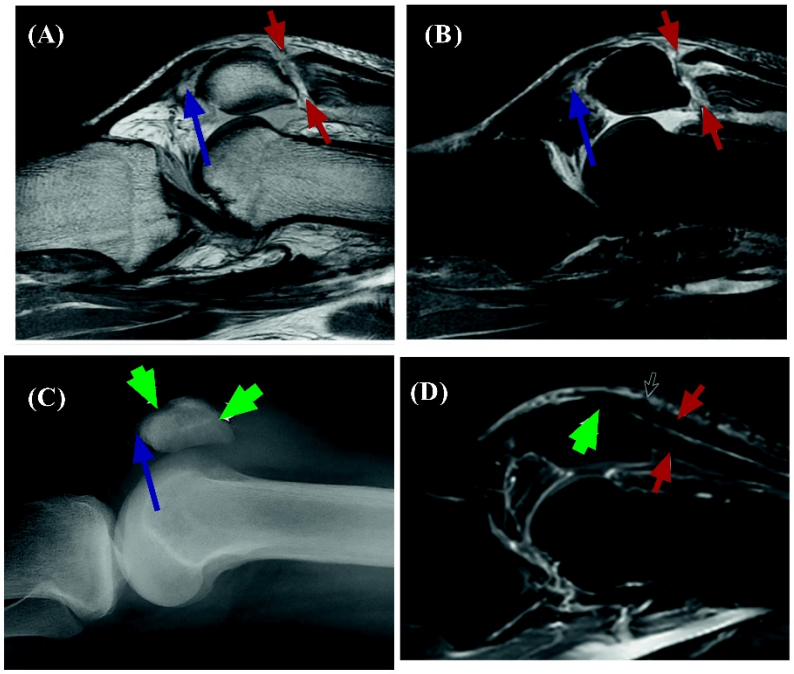


Figure 2. A case study of a 28-year-old male with a QT tear. Section A shows the medial-weighted MR image without fat saturation and Section B with fat saturation at the osseotendinous junction (red arrows). The blue arrows show a partial tear occurring at the proximal patellar tendon. This patient was subjected to surgical treatment using a transpatellar bone tunnel tendon fixing technique (green arrows) within 1 month of follow-up (section C). Additionally, in section C, ossification occurs at the tear of the proximal patellar tendon (red arrows). In section D, the T1-axial fat-saturated MR images after 36 months of surgery reveal an intact QT (red arrows) a post-operative artifact (blue arrows), and ossified surgical tunnels (green arrows).

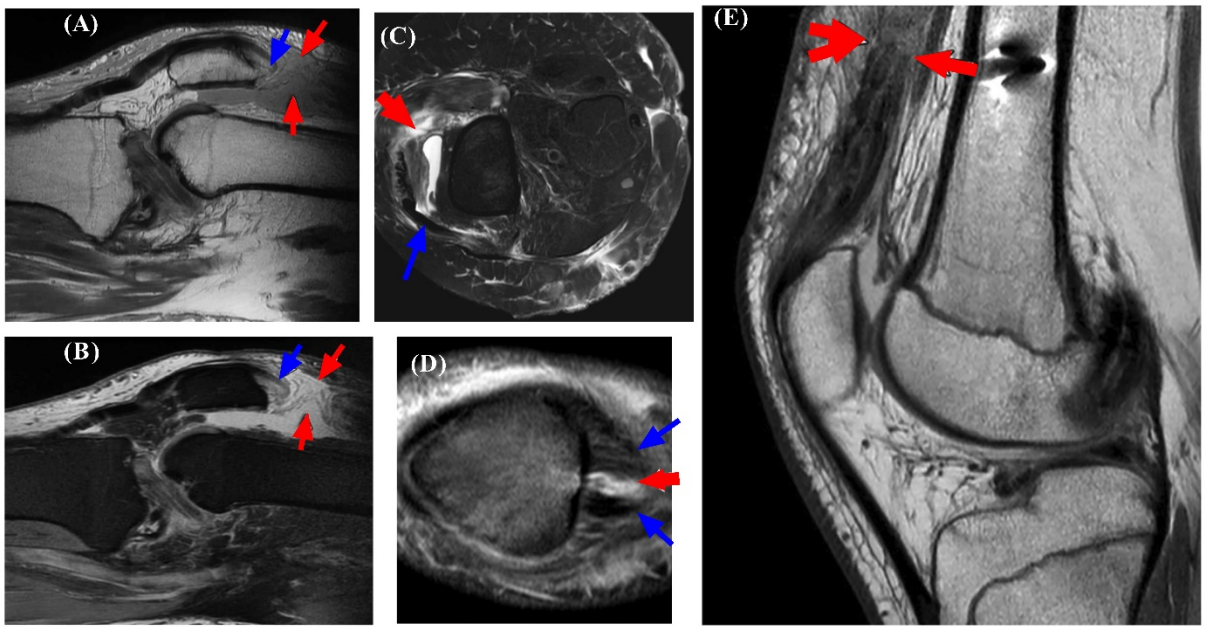


Figure 3. A case study of a 40-year-old male athlete with QT tear who was subjected to surgical treatment based on end-to-end tendinous repair showing medial-weighted MR image without fat-saturation in sections A & B with the rupture occurring at the myotendinous junction (red arrows). Section C shows a rupture of the right QT with the axial T2-weighted fat-saturated MR image showing total disruption of the vastus medialis tendon (red arrows) while the vastus lateralis remained intact (blue arrows). In section D, there is a partial rupture of the QT with the coronal medial-weighted fat-saturated MR image revealing a partial tear of the rectus femoris (red arrows) while the lateral and middle sections remain unaffected (blue arrows). Lastly, section E shows a male QT tear subjected to surgical end-to-end repair with the intermediate-weighted non-fat saturated MR image showing a complete rupture occurring at the myotendinous junction (red arrows)

Table 1. Quality assessment of each tendon in the QT group as a percentage of the total in all sub-categories of normal, tendinosis, partial, and complete tear.

Quadriceps Femoris Tendon	Normal	Tendinosis	Partial Tear	Complete Tear	Inter-reader Agreement (κ)
Rectus Femoris	10.4% (5/53)	9.4% (5/53)	22.6% (12/53)	57.6% (31/53)	0.808
Vastus Medialis	3.8% (2/53)	13.2% (7/53)	23.1% (12/53)	59.9% (32/53)	0.761
Vastus Lateralis	13.2% (7/53)	11.3% (6/53)	30.2% (16/53)	45.3% (24/53)	0.787
Vastus Intermedius	22.6% (12/53)	9.4% (5/53)	41.5% (22/53)	26.5% (14/53)	0.687

Table 2. Quality Analysis of the Distal Tear Characterisation and rupture types in QT based on Patellar Avulsion Injury

Quadriceps Femoris Tendon	No Avulsion (Mean)	Avulsion (Mean)	p-value
Rectus Femoris	3.42	3.23	0.028*
Vastus Medialis	3.32	3.12	0.022*
Vastus Lateralis	3.48	3.20	0.015*
Vastus Intermedius	2.98	3.00	0.714

Note: *$p < 0.05$

Table 3. Tear location for each QT tendon as a proportion of the Total in each category

Location	Rectus Femoris	Vastus Medialis	Vastus Lateralis	Vastus Intermedius
Bony Avulsion	5.1% (3/53)	11.3% (6/53)	10.4% (5/53)	5.7% (3/53)
Directly at the Patella	42.2% (22/53)	45.3% (24/53)	38.5% (20/53)	34.0% (18/53)
Proximal to the Patella	50.6% (27/53)	39.6% (21/53)	47.2% (25/53)	58.5% (31/53)
Myotendinous Junction	2.1% (1/53)	3.8% (2/53)	3.8% (2/53)	1.9% (1/53)
Inter-reader Agreement	$\kappa = 0.675$	$\kappa = 0.611$	$\kappa = 0.667$	$\kappa = 0.631$

Table 4. Quality Assessment of the AT Rupture tendons as a percentage of the total in all sub-categories of normal, tendinosis, partial, and complete tear.

Sub-component	Normal (%)	Tendinosis (%)	Partial Tear (%)	Complete Tear (%)	Inter-reader Agreement (κ)

Gastrocnemius (Lateral Head)	8.0% (4/53)	12.1% (6/53)	18.1% (9/53)	14.9% (8/53)	0.765
Gastrocnemius (Medial Head)	10.0% (5/53)	11.3% (6/53)	16.0% (8/53)	15.9% (8/53)	0.742
Soleus	13.0% (7/53)	9.0% (5/53)	15.1% (8/53)	15.9% (8/53)	0.731
Enthesis	6.5% (3/53)	6.0% (3/53)	13.4% (7/53)	27.2% (14/53)	0.698

Table 5: Quality Assessment of the AT Rupture tendons as a percentage of the total in all sub-categories of Bony Avulsion, Mid-Substance Rupture, Insertional Rupture, and Musculotendinous Junction Rupture.

Sub-component	**Bony Avulsion (%)**	**Mid-Substance Rupture (%)**	**Insertional Rupture (%)**	**Musculotendinous Junction Rupture (%)**
Gastrocnemius (Lateral Head)	5.7% (3/53)	13.2% (7/53)	69.8% (37/53)	11.3% (6/53)
Gastrocnemius (Medial Head)	4.7% (2/53)	14.9% (8/53)	66.0% (35/53)	14.4% (7/53)
Soleus	2.8% (1/53)	20.8% (11/53)	56.6% (30/53)	20.8% (11/53)

Enthesis	30.2% (16/53)	3.8% (2/53)	61.5% (32/53)	4.7% (2/53)