

RESEARCH

Open Access



Investigation of the effects of morphometric characteristics of the foot on Achilles tendon rupture

Osman Hanbeyoğlu^{1*}, Mustafa Canbolat² and Veysel Burulday³

Abstract

Background Foot morphology plays a critical role in load distribution within the foot–Achilles tendon complex. However, the relationship between specific angular morphometric characteristics of the foot and Achilles tendon rupture (ATR) remains incompletely understood.

Methods In this retrospective study, non–weight-bearing lateral foot radiographs of 147 male individuals aged ≥ 25 years were evaluated. The rupture group consisted of 72 patients diagnosed with ATR, and the control group included 75 healthy individuals with no prior history of trauma or rupture. A total of five angular foot morphometric parameters were assessed. Between-group comparisons were performed using independent t-tests or Mann–Whitney U tests, as appropriate.

Results Significant differences between the rupture and control groups were observed in the Hibbs angle ($124.49 \pm 9.52^\circ$ vs. $128.10 \pm 7.58^\circ$; $p = 0.012$), Talar ground angle ($20.29 \pm 5.66^\circ$ vs. $23.48 \pm 4.69^\circ$; $p < 0.001$), Meary angle ($12.55 \pm 5.78^\circ$ vs. $7.13 \pm 4.81^\circ$; $p < 0.001$). No significant differences were detected for the remaining angular parameters.

Conclusions Several angular foot alignment parameters differed between individuals with ATR and healthy controls. Significant differences between individuals with Achilles tendon rupture and healthy controls were identified in the talar ground angle, Meary angle, and Hibbs angle. These findings indicate that sagittal plane foot alignment, particularly longitudinal arch configuration and talar–first metatarsal orientation, may be associated with Achilles tendon rupture.

Keywords Achilles tendon rupture, Foot biomechanics, Radiographic measurement

*Correspondence:

Osman Hanbeyoğlu
o.sap@alparslan.edu.tr

¹Faculty of Health Science, Department of Nursing, Muş Alparslan University, Muş, Turkey

²Faculty of Medicine, Department of Anatomy, Inonu University, Malatya, Turkey

³Faculty of Medicine, Department of Radiology, Inonu University, Malatya, Turkey



© The Author(s) 2026. **Open Access** This article is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License, which permits any non-commercial use, sharing, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if you modified the licensed material. You do not have permission under this licence to share adapted material derived from this article or parts of it. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by-nc-nd/4.0/>.

Introduction

The morphological characteristics of the human foot, a crucial component of bipedal locomotion, have long attracted the attention of anatomists, clinicians, and palaeontologists alike [1]. Through its complex anatomical organisation, the foot plays fundamental biomechanical roles in locomotor activities such as walking and running, distributing body weight across the plantar surface while functioning as a lever that assists in forward propulsion [2]. Within this system, the Achilles tendon is a key structure, enhancing the mechanical advantage of the plantar flexor muscles and contributing substantially to propulsive force generation [3].

The Achilles tendon transmits forces generated by the posterior compartment muscles to the heel and experiences high mechanical loads during daily and sports activities. During gait, forces of approximately 2,600 N are produced, increasing to 3,800 N during jumping and up to 9,000 N during sprinting [4]. Owing to its unique anatomical and biomechanical properties, the Achilles tendon is prone to injury [5]. Epidemiological data indicate that Achilles tendon rupture affects 7–40 individuals per 100,000 annually, predominantly men between 30 and 40 years of age, most frequently during sports involving intense lower-limb activity [6–8]. The male-to-female incidence ratio is approximately 4:1 [9].

Research on the biomechanics of the foot Achilles tendon lever system has highlighted the role of foot structure, including arch configuration and rearfoot alignment, in locomotor efficiency and tendon loading [10, 11]. Early biomechanical models and in vivo studies have clarified the contributions of the Achilles tendon moment arm and foot lever mechanics to propulsion and energy efficiency [12, 13], with practical relevance for pathological gait, rehabilitation, and prosthetic and robotic design [14–17].

Despite extensive research, the pathways linking variations in foot morphology such as arch height, foot posture, and rearfoot alignment to Achilles tendon rupture remain incompletely understood [15, 18, 19]. Evidence regarding whether pronated or supinated foot postures predispose individuals to tendon injury remains conflicting [20, 21], and the effects of gait-related factors

on tendon loading and morphology remain a matter of debate [22–24]. Furthermore, individual variations in tendon structure, may further complicate the assessment of injury susceptibility [25, 26].

Despite the widespread use of angular radiographic parameters in the assessment of foot and ankle pathology, relatively few studies have systematically evaluated their association with Achilles tendon rupture. The relevance of these parameters commonly applied in the evaluation of foot alignment and hindfoot malalignment to ATR has not been comprehensively investigated.

Accordingly, the present study aimed to evaluate differences in selected angular foot morphometric parameters between individuals with Achilles tendon rupture and healthy controls using radiographic measurements. We hypothesized that selected angular foot morphometric parameters might differ between patients with Achilles tendon rupture and healthy individuals.

Methods

Study population and sample

This retrospective study was conducted using radiographic images of consecutive patients aged 25 years and older who presented to a tertiary hospital in Turkey between January 2019 and January 2023. All individuals who met the predefined inclusion criteria during the study period were included, yielding a final study cohort of 147 participants, consisting of 72 patients with Achilles tendon rupture and 75 healthy controls (Table 1).

The minimum required sample size was estimated using G*Power software (version 3.1.9.4). Assuming a medium effect size (0.5), a significance level of 5%, and a statistical power of 80%, the minimum sample size was calculated as 128 participants.

Patients were allocated into two independent groups: a rupture group comprising patients diagnosed with Achilles tendon rupture and a control group consisting of individuals without Achilles tendon pathology. No individual was included in both groups.

As only one female patient was present in the rupture group, sex-based subgroup analyses were not considered statistically meaningful. Accordingly, comparative analyses were primarily conducted in the male patient population.

Due to the retrospective design of the study and limitations of hospital medical records, only basic demographic variables (age and sex) were available. Information on height, weight, body mass index, physical activity level, smoking status, occupational loading, and sports participation could not be reliably retrieved and was therefore not included in the analyses. The inclusion and exclusion criteria applied in this study are detailed below.

Inclusion criteria age ≥ 25 years; presentation between January 2019 and January 2023; and availability of a

Table 1 Flow of participants through the study

Stage	n	Reason / Description
Assessed for eligibility	173	Consecutive patients (January 2019 – January 2023)
Excluded	26	Incomplete or poor-quality radiographs, Missing clinical or demographic data
Included in the final cohort	147	Met predefined inclusion criteria
Allocated to rupture group	72	Achilles tendon rupture
Allocated to control group	75	Healthy controls

non-weight-bearing lateral foot radiograph of sufficient quality for angular morphometric assessment. The rupture group included patients diagnosed with Achilles tendon rupture, whereas the control group consisted of individuals with no history of Achilles tendon pathology.

Exclusion criteria for both groups were: incomplete or poor-quality radiographs precluding reliable landmark identification; non-standard radiographic projections; prior foot, ankle, or Achilles tendon surgery; major post-traumatic deformity or severe structural abnormalities that could affect angular measurements; and missing basic demographic data (age or sex).

Radiographic evaluation and data collection

The foot radiographs analyzed in this study were retrospectively obtained from patients who underwent routine radiographic evaluation following acute trauma or injury-related hospital admission. In accordance with standard clinical practice in emergency and outpatient settings, non-weight-bearing radiography is typically the initial imaging modality for the assessment of foot and ankle injuries [27]. Accordingly, non-weight-bearing lateral foot radiographs were retrieved and analyzed using the hospital's Picture Archiving and Communication System (PACS).

All measurements were performed based exclusively on established angular parameters commonly used to evaluate foot morphology and its anatomical relationship with the Achilles tendon. Measurements were obtained using standardized radiographic techniques to ensure consistency and reproducibility.

Morphometric parameters and measurements

Five angular morphometric parameters were measured on lateral foot radiographs to evaluate foot bony alignment and its anatomical relationship with the Achilles tendon (Fig. 1). All parameters were selected based on previously published radiographic assessment methods widely used in the evaluation of foot biomechanics and sagittal plane alignment.

All angular measurements were performed by a single observer, Prof. Dr. Veysel BURULDAY, an experienced musculoskeletal radiologist, using standardized measurement protocols based on predefined anatomical reference points. The observer was blinded to group allocation at the time of measurement. All assessments were conducted using the same imaging modality, identical imaging planes, and consistent measurement settings to ensure measurement consistency and reproducibility.

Fowler–Philip Angle (FPA) The angle formed between a line drawn along the plantar surface of the calcaneus and a line tangent to the posterior aspect of the calcaneal tuberosity was measured [28].

Talar Ground Angle (TGA) The angle between the mid-tarsal line and the supporting surface was measured [29].

Hibbs Angle (HA) Also known as the calcaneus–first metatarsal angle. It was defined as the angle between a line tangent to the plantar surface of the calcaneus and the longitudinal axis of the first metatarsal [30].

Meary Angle (MA) The angle between the longitudinal axis of the talus and the axis of the first metatarsal bone was measured [31].

Calcaneal Pitch Angle (CPA) Also known as the calcaneal inclination angle. It was measured between a line along the supporting surface and a line tangent to the plantar surface of the calcaneus [32].

Measurement tools

Digital radiographic images were obtained from the hospital's Picture Archiving and Communication System (PACS). All morphometric measurements were performed using the integrated linear and angular measurement modules of the PACS software.

Statistical analysis

All statistical analyses were performed using IBM SPSS Statistics version 25.0 (IBM Corp., Armonk, NY, USA). Data distribution was assessed using the Kolmogorov–Smirnov test. Continuous variables were expressed as mean $\pm$ standard deviation (SD). Between-group comparisons were performed using the independent samples t-test for normally distributed variables and the Mann–Whitney U test for non-normally distributed variables. Effect sizes for between-group differences were calculated using Cohen's *d*.

Results

The mean age of the control group was 37.19 ± 12.63 years (range, 25–75 years), while the mean age of the rupture group was 37.88 ± 11.25 years (range, 25–76 years), indicating comparable age distributions between groups (Table 2).

Comparisons of angular morphometric parameters between the rupture and control groups are presented in Table 3. No statistically significant differences were observed between the groups for the FPA and the CPA ($p > 0.05$).

In contrast, statistically significant between-group differences were identified for the HA, TGA and MA. Specifically, HA and TGA values were significantly higher in the control group, whereas MA value were significantly higher in the rupture group (HA: $p = 0.012$, $d = 0.42$; TGA: $p < 0.001$, $d = 0.61$; MA: $p < 0.001$, $d = 1.00$). The largest between-group difference was observed for

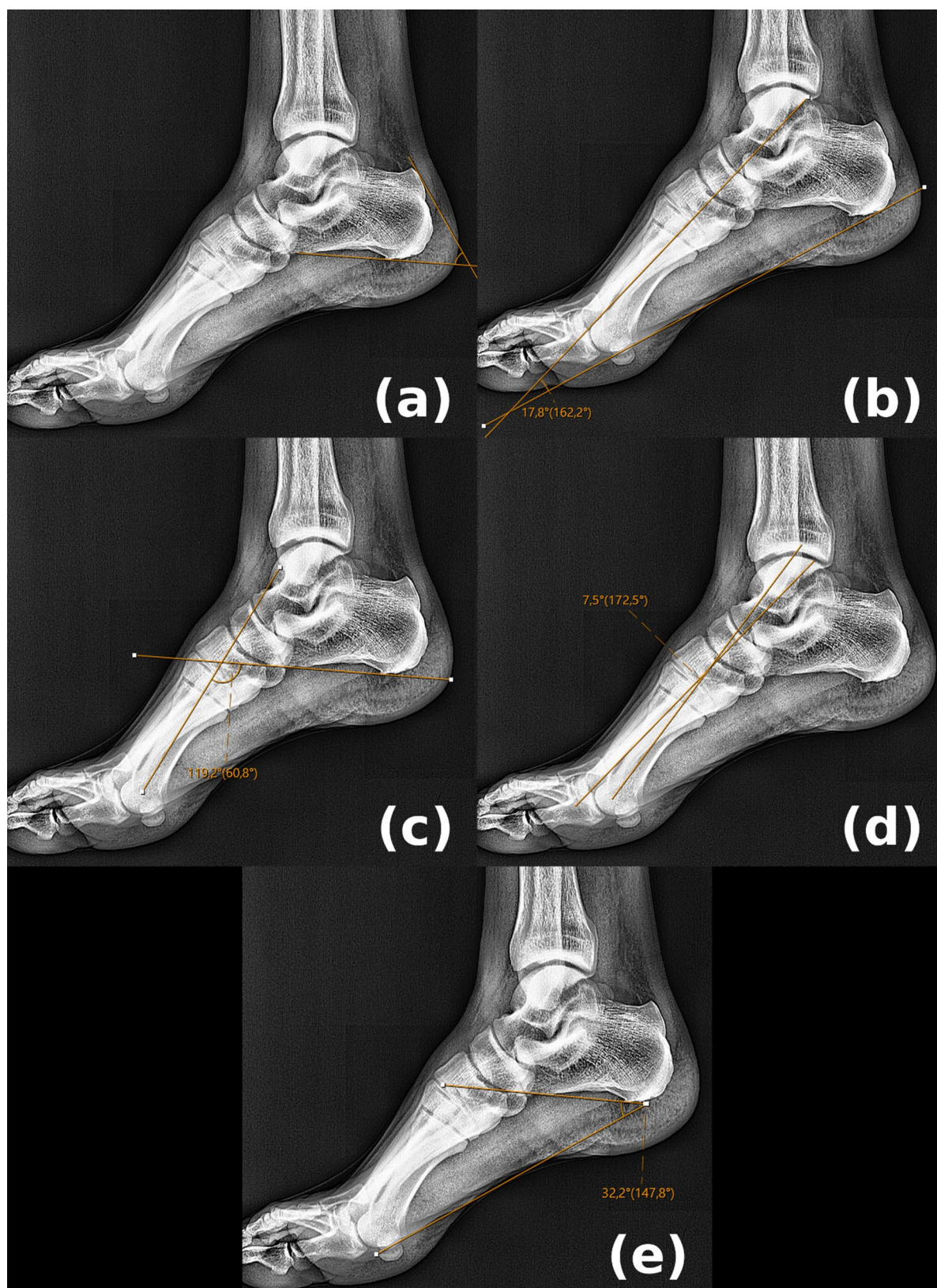


Fig. 1 Angular morphometric measurements performed on lateral foot radiographs. **(a)** Fowler-Philip Angle (FPA); **(b)** Talar Ground Angle (TGA); **(c)** Hibbs Angle (HA); **(d)** Meary Angle (MA); **(e)** Calcaneal Pitch Angle (CPA)

Table 2 Age distribution of the control and rupture groups

Groups	Mean $\pm$ SD (Years)	Min.	Max.
Control Group (n = 75)	37.19 $\pm$ 12.63	25	75
Rupture Group (n = 72)	37.88 $\pm$ 11.25	25	76

TGA ($p < 0.001$, 95% CI: 1.50 to 4.88), followed by MA ($p < 0.001$, 95% CI: -7.17 to -3.67). The remaining significant differences showed small to moderate effect sizes (Table 3).

Discussion

This study contributes to the limited body of literature investigating the association between foot alignment and Achilles tendon rupture using radiographic angular measurements. Comparisons between the rupture and control groups demonstrated statistically significant differences in selected angular parameters, suggesting that variations in sagittal plane foot alignment may be present in individuals with Achilles tendon rupture. However, the magnitude of these differences was relatively modest; therefore, the findings should be interpreted cautiously and not as evidence of a direct causal relationship.

The observed differences, particularly in parameters reflecting sagittal plane alignment such as the TGA, MA, and HA, may indicate alterations in the biomechanical behavior of the foot Achilles tendon complex. Changes in longitudinal arch alignment and talar first metatarsal orientation could potentially influence load transmission characteristics along the Achilles tendon. When interpreted in the context of existing biomechanical knowledge, these findings suggest that individual variations in foot alignment may contribute to differences in tendon loading patterns, rather than acting as isolated or deterministic factors for rupture.

Among the evaluated angular parameters, the TGA and MA demonstrated the most pronounced between-group differences. The lower TGA observed in the rupture group may reflect alterations in talar orientation

relative to the supporting surface, potentially influencing sagittal plane alignment and load transmission characteristics. Similarly, the higher MA indicates deviations in longitudinal arch alignment that may affect biomechanical behavior within the foot Achilles tendon complex. Previous biomechanical studies have shown that alterations in talar alignment and medial arch configuration can modify load transmission through the posterior chain and increase localized tendon strain [33–35]. In this context, the present findings suggest that variations in sagittal plane foot alignment may be associated with altered Achilles tendon loading patterns rather than acting as isolated determinants of rupture.

The observed differences in MA are consistent with previous studies linking Meary's angle to longitudinal arch alignment and Achilles tendon morphology. Pronatory or valgus tendencies reflected by MA have been shown to alter medial–lateral load distribution along the posterior kinetic chain, potentially increasing localized strain within specific regions of the tendon [36]. These findings support the interpretation that deviations in sagittal plane alignment may influence Achilles tendon biomechanics.

The HA, which also differed significantly between groups, is an important parameter reflecting foot structure and arch integrity. Reduced HA values have previously been associated with diminished medial arch stability, altered plantar pressure distribution, and increased Achilles tendon loading [15, 37, 38]. Furthermore, structural alterations in foot alignment following Achilles tendon injury have been reported to persist and may influence long-term functional outcomes [39–41]. The lower HA values observed in the rupture group are therefore consistent with previously described associations between reduced arch stability and increased mechanical demand on the Achilles tendon.

In contrast, no significant between-group differences were observed for the FPA or calcaneal pitch angle CPA.

Table 3 Comparison of angle measurements by group

Measurement (°)	Control Group Mean $\pm$ SD (Min–Max)	Rupture Group Mean $\pm$ SD (Min–Max)	Mean Diff.	95% CI	t	p
FPA	50.72 $\pm$ 6.65 (36.60–67.50)	52.44 $\pm$ 6.31 (33.40–63.80)	–1.72	–3.83 to 0.39	–1.60	0.110
HA	128.10 $\pm$ 7.58 (110.60–151.20)	124.49 $\pm$ 9.52 (101.80–159.00)	3.60	0.80 to 6.41	2.54	0.012*
CPA	24.66 $\pm$ 5.82 (9.40–37.60)	25.66 $\pm$ 6.20 (12.10–43.30)	–1.00	–2.96 to 0.95	–1.01	0.312
TGA	23.48 $\pm$ 4.69 (13.80–32.60)	20.29 $\pm$ 5.66 (10.00–38.00)	3.19	1.50 to 4.88	3.72	<0.001*
MA	7.13 $\pm$ 4.81 (0.10–20.80)	12.55 $\pm$ 5.87 (1.40–27.30)	–5.42	–7.16 to -3.67	–6.13	<0.001*

Note: FPA Fowler–Philip Angle, TGA Talar Ground Angle, HA Hibbs Angle, MA Meary Angle, CPA Calcaneal Pitch Angle

* Statistically significant at ($p < 0.05$)

This finding aligns with heterogeneous and sometimes conflicting evidence regarding the role of static foot posture parameters in Achilles tendon pathology [42–44]. Collectively, these results support the concept that Achilles tendon rupture is unlikely to be attributable to a single angular parameter and instead reflects a multifactorial biomechanical process.

One of the strengths of this study is the systematic evaluation of multiple radiographic angular alignment parameters using standardized measurement techniques. Nevertheless, the retrospective design and relatively limited sample size restrict causal inference. Variability in imaging techniques and measurement protocols further underscores the importance of standardized assessment methods to improve reproducibility and comparability across studies [45, 46].

Although several angular parameters differed significantly between groups, the absolute differences were relatively small, and their clinical relevance should therefore be interpreted cautiously. Accordingly, the present findings should be considered hypothesis-generating and warrant confirmation in prospective studies incorporating comprehensive biomechanical and clinical covariates.

Limitations

This study has several limitations. First, the use of non-weight-bearing radiographs represents a methodological constraint, as dynamic alterations in foot arch configuration and hindfoot alignment under physiological loading conditions could not be assessed. The inclusion of weight bearing imaging techniques would enable a more comprehensive evaluation of the functional characteristics of foot morphology and should be considered in future prospective investigations.

Second, due to the retrospective design and the limited scope of hospital medical records, only basic demographic data (age and sex) were available. Information regarding height, weight, body mass index (BMI), physical activity level, smoking status, occupational loading, and sports participation factors known or potentially associated with Achilles tendon rupture risk was not systematically recorded and therefore could not be incorporated into the analyses. This limitation precluded statistical adjustment for potential confounding variables and restricts the interpretation of the findings.

Finally, because only one female patient was identified in the rupture group, sex-specific subgroup analyses could not be performed in a statistically reliable manner. Consequently, comparative analyses were conducted primarily within the male population, which limits the generalizability of the results to female individuals.

Conclusion

Significant differences between individuals with Achilles tendon rupture and healthy controls were identified in the talar ground angle, Meary angle, and Hibbs angle. These findings indicate that sagittal plane foot alignment, particularly longitudinal arch configuration and talar–first metatarsal orientation, may be associated with Achilles tendon rupture. However, these associations should not be interpreted as causal and require confirmation in well-designed prospective studies.

Acknowledgements

The authors would like to thank the Department of Radiology for their support during the imaging evaluation process. An artificial intelligence–based language model (ChatGPT, OpenAI) was used solely for language editing and improvement of grammar and clarity. The authors take full responsibility for the scientific content of the manuscript.

Clinical trial number

Not applicable.

Authors' contributions

OH and MC conceived and designed the study. OH and VB performed the data collection and measurements. OH conducted the statistical analysis. OH and MC interpreted the data. OH drafted the manuscript. All authors critically revised the manuscript and approved the final version.

Funding

The authors received no specific funding for this work.

Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki. Ethical approval was obtained from the Muş Alparslan University Scientific Research and Publication Ethics Committee (Meeting Date: 08 November 2023; Meeting No: 9; Decision No: 73). Due to the retrospective design of the study, informed consent was waived by the ethics committee.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Received: 18 December 2025 / Accepted: 18 February 2026

Published online: 24 February 2026

References

1. Kramer PA, Lautzenheiser SG. Foot morphology influences the change in arch index between standing and walking conditions. *Anat Rec*. 2022;305(11):3254–62.
2. Conconi M, Pompili A, Sancisi N, Durante S, Leardini A, Belvedere C. Foot kinematics as a function of ground orientation and weightbearing. *J Orthop Research*. 2024;42(1):148–63.
3. O'Brien M. The anatomy of the Achilles tendon. *Foot Ankle Clin*. 2005;10(2):225–38.
4. Winnicki K, Ochala-Kłos A, Rutowicz B, Pękala PA, Tomaszewski KA. Functional anatomy, histology and biomechanics of the human Achilles

- tendon—A comprehensive review. *Annals Anatomy-Anatomischer Anzeiger*. 2020;229:151461.
5. Wohlfert AJ, Garcia MAF, Luckett BS, Anton SR, Vranish JR. Comparison Of Vascular Anatomy, Strain Patterns, And Ultimate Tensile Strength Across Cadaveric Achilles Tendons: 1698. *Med Sci Sports Exerc*. 2023;55(9S):569–70.
 6. Lantto I, Heikkinen J, Flinkkilä T, Ohtonen P, Leppilahti J. Epidemiology of A chilles tendon ruptures: Increasing incidence over a 33-year period. *Scand J Med Sci Sports*. 2015;25(1):e133–8.
 7. 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. *Orthop J sports Med*. 2018;6(11):2325967118808238.
 8. Mazza D, Annibaldi A, Monaco E, Carrozzo A, Princi G, Fenucci S, et al. Achilles tendon rupture in professional football player: an Epidemiological study in European championship with a mid-term follow-up. *Muscles, Ligaments Tendons J (MLTJ)*. 2022;12(4):478–83.
 9. Hess GW. Achilles tendon rupture: a review of etiology, population, anatomy, risk factors, and injury prevention. *Foot Ankle Spec*. 2010;3(1):29–32.
 10. Blazeovich AJ, Fletcher JR. More than energy cost: multiple benefits of the long Achilles tendon in human walking and running. *Biol Rev*. 2023;98(6):2210–25.
 11. D'Hondt L, De Groote F, Afschrift M. A dynamic foot model for predictive simulations of gait reveals causal relations between foot structure and whole body mechanics. *bioRxiv*. 2023;2023(03):22–533790.
 12. Lee SS, Piazza SJ. Built for speed: musculoskeletal structure and sprinting ability. *J Exp Biol*. 2009;212(22):3700–7.
 13. Maganaris CN, Baltzopoulos V, Sargeant AJ. In vivo measurement-based estimations of the human Achilles tendon moment arm. *Eur J Appl Physiol*. 2000;83(4):363–9.
 14. Buchmann A, Kiss B, Badri-Spröwitz A, Renjewski D, editors. Power to the springs: Passive elements are sufficient to drive push-off in human walking. *Climbing and Walking Robots Conference*; 2022: Springer.
 15. Thuesen AH. Rearfoot Biomechanics in Achilles Tendon Function. University of Salford (United Kingdom); 2015.
 16. Giddings VL, Beupre GS, Whalen RT, Carter DR. Calcaneal loading during walking and running. *Med Sci Sports Exerc*. 2000;32(3):627–34.
 17. Reiter AJ, Martin JA, Knurr KA, Adamczyk PG, Thelen DG. Achilles tendon loading during running estimated via shear wave tensiometry: a step towards wearable kinetic analysis. *Med Sci Sports Exerc*. 2024;56(6):1077.
 18. Mokhtari Malekabadi A, Jafarnezhadgero A, Gghorbanlou F. The effects of changing footstrike pattern on the amplitude and frequency spectrum of ground reaction forces during running in individuals with pronated feet. *Phys Treatments-Specific Phys Therapy J*. 2020;10(4):205–12.
 19. Murley G, Tan J, Edwards R, De Luca J, Munteanu SE, Cook JL. Foot posture is associated with morphometry of the peroneus longus muscle, tibialis anterior tendon, and A chilles tendon. *Scand J Med Sci Sports*. 2014;24(3):535–41.
 20. Leppilahti J, Korpelainen R, Karpakka J, Kvist M, Orava S. Ruptures of the Achilles tendon: relationship to inequality in length of legs and to patterns in the foot and ankle. *Foot Ankle Int*. 1998;19(10):683–7.
 21. Munteanu SE, Barton CJ. Lower limb biomechanics during running in individuals with achilles tendinopathy: a systematic review. *J Foot Ankle Res*. 2011;4(1):15.
 22. Almonroeder T, Willson JD, Kernozek TW. The effect of foot strike pattern on Achilles tendon load during running. *Ann Biomed Eng*. 2013;41(8):1758–66.
 23. Hashizume S, Yanagiya T. A forefoot strike requires the highest forces applied to the foot among foot strike patterns. *Sports Med Int Open*. 2017;1(02):E37–42.
 24. Yong JR, Dembia CL, Silder A, Jackson RW, Fredericson M, Delp SL. Foot strike pattern during running alters muscle-tendon dynamics of the gastrocnemius and the soleus. *Sci Rep*. 2020;10(1):5872.
 25. Knaus KR, Blemker SS. 3D models reveal the influence of achilles subtendon twist on strain and energy storage. *Front Bioeng Biotechnol*. 2021;9:539135.
 26. Mylle I, Funaro A, Crouzier M, Bogaerts S, Vanwanseele B. Achilles tendon compliance influences tendon loading more than Achilles tendon twist in Achilles tendinopathy: a musculoskeletal modeling approach. *Front Bioeng Biotechnol*. 2024;12:1399611.
 27. Gu J, Patel S, Kumaravel M. Imaging of Ankle and Foot Injuries. In: Patlas MN, Katz DS, Scaglione M, editors. *Atlas of Emergency Imaging from Head-to-Toe*. Cham: Springer Nature Switzerland; 2025. pp. 671–89.
 28. Tourné Y, Baray A-L, Barthélémy R, Moroney P. Contribution of a new radiologic calcaneal measurement to the treatment decision tree in Haglund syndrome. *Orthop Traumatology: Surg Res*. 2018;104(8):1215–9.
 29. Vanderwilde R, Staheli L, Chew D, Malagon V. Measurements on radiographs of the foot in normal infants and children. *JBJS*. 1988;70(3):407–15.
 30. Mosca VS. Principles and management of pediatric foot and ankle deformities and malformations. Lippincott Williams & Wilkins; 2014.
 31. AbdelMassih A, Hozaien R, Mishriky F, Michael M, AmanAllah M, Ali N, et al. Meary angle for the prediction of mitral valve prolapse risk in non-syndromic patients with pes planus, a cross-sectional study. *BMC Res Notes*. 2022;15(1):145.
 32. Bagdeliöglu K. Radiologic and demographic characteristics of patients with plantar calcaneal spur. *J Foot Ankle Surg*. 2021;60(1):51–4.
 33. Karaismailoglu B, Peiffer M, Sharma S, Burssens A, Waryasz G, Guss D, et al. Effect of Dorsal Closing Wedge Calcaneal Osteotomy on Foot Alignment and Biomechanics in Patients with Insertional Achilles Tendinopathy. *Foot Ankle Orthop*. 2023;8(4):2473011423S00034.
 34. Matsui T, Kumai T, Kamijo S, Shinohara Y, Kurokawa H, Taniguchi A, et al. Effect of ankle motion and tensile stress at the Achilles tendon on the contact pressure between the Achilles tendon and the calcaneus. *J Foot Ankle Surg*. 2021;60(4):753–6.
 35. Nunes GA, Carvalho KA, Mansur NSB, Kim KC, Chrea B, Mann TS, et al. Semi-automatic 3D assessment of Zadek osteotomy effects. *Foot ankle Orthop*. 2023;8(4):2473011423S00407.
 36. Sobhani S, Hijmans J, van den Heuvel E, Zwerver J, Dekker R, Postema K. Biomechanics of slow running and walking with a rocker shoe. *Gait Posture*. 2013;38(4):998–1004.
 37. Gołos-Lewandowska J, Kwiatkowski K, Cieślak P. Structure and function of the foot in the context of Achilles tendon rupture—cause-effect analysis. 2024.
 38. Skypala J, Hamill J, Sebera M, Elavsky S, Monte A, Jandacka D. Running-related Achilles tendon injury: a prospective biomechanical study in recreational runners. *J Appl Biomech*. 2023;39(4):237–45.
 39. Brorsson A, Sædis Jónsdóttir U, Nygren D, Larsson N, Tranberg R. The injured limb presents lower values in foot structure measurements 6 years after an Achilles tendon rupture. *Muscles, Ligaments & Tendons J (MLTJ)*. 2021;11(4):694–703.
 40. Malakoutikhah H, Latt LD. The Impact of Tendon Lengthening Following Achilles Tendon Repair on Foot Kinetics, a Finite Element Analysis. *Foot Ankle Orthop*. 2023;8(4):2473011423S00429.
 41. Edama M, Takabayashi T, Inai T, Kikumoto T, Ito W, Nakamura E, et al. Differences in the strain applied to Achilles tendon fibers when the subtalar joint is overpronated: a simulation study. *Surg Radiol Anat*. 2019;41(5):595–9.
 42. Aubol KG, Milner CE. Whipping or tearing? The biomechanics of Achilles tendinopathy in rearfoot strike runners. *Foot*. 2024;59:102082.
 43. Reule CA, Alt WW, Lohrer H, Hochwald H. Spatial orientation of the subtalar joint axis is different in subjects with and without Achilles tendon disorders. *Br J Sports Med*. 2011;45(13):1029–34.
 44. Silva RS, Smitheman HP, Smith AK, Silbernagel KG. Are static foot posture and ankle dorsiflexion range of motion associated with Achilles tendinopathy? A cross-sectional study. *Braz J Phys Ther*. 2022;26(6):100466.
 45. Jenko N, Ariyaratne S, Azzopardi C, Iyengar K, Prem H, Nischal N, et al. Radiological angle assessment of Haglund's deformity: validation on Magnetic Resonance Imaging. *Foot*. 2024;59:102096.
 46. Nakajima K. Insertional Achilles tendinopathy: A radiographic cross-sectional comparison between symptomatic and asymptomatic heel of 71 patients. *Eur J Radiol Open*. 2024;12:100568.

Publisher's note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.