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Justyna Gołos-Lewandowska, Krzysztof Kwiatkowski, Piotr Cieślik

Structure and function of the foot in the context of Achilles tendon rupture – cause-effect analysis

Budowa i czynność stopy a zerwanie ścięgna Achillesa – analiza przyczynowo-skutkowa

Department of Traumatology and Orthopaedics, Military Institute of Medicine – National Research Institute, Warsaw, Poland
Correspondence: Justyna Gołos-Lewandowska, Department of Traumatology and Orthopaedics, Military Institute of Medicine – National Research Institute, Szaserów 128, 04-141 Warsaw, Poland, e-mail: jgolos@wim.mil.pl

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ORCID iDs
1. Justyna Gołos-Lewandowska https://orcid.org/0009-0004-6506-167X
2. Krzysztof Kwiatkowski https://orcid.org/0000-0003-0898-1061

Abstract

Introduction and objective: Achilles tendon rupture is the most common sports injury. The aim of the study was to analyse the cause-effect correlation between the occurrence of foot dysfunction and Achilles tendon rupture in male athletes. **Materials and methods:** The study included 41 men who were treated for Achilles tendon rupture, and a control group of 40 men who met the same criteria, but had no history of Achilles tendon rupture. Each participant underwent the following examinations: orthopaedic examination, plain standing foot radiographs, and foot examination on the gait platform. The final stage was an experimental study in the field of biomechanics of the musculoskeletal system of the lower limbs, with an assessment of forces arising in the Achilles tendon and statistical analyses of all obtained results. **Results:** Plain foot radiographs and examination on the gait platform showed that the feet in the study group had significantly more abnormalities compared to the control group. Planovalgus foot deformity was far more frequent in the study group on plain radiographs. The forefoot was overloaded much more often in the study group, and the foot was placed in excessive abduction, which is characteristic of planovalgus foot. The experimental study shows that the force in the Achilles tendon increases with increasing load on the forefoot. **Conclusions:** Planovalgus foot deformity in male athletes with a history of ruptured Achilles tendon is the most common foot pathology, significantly increasing the forces transmitted by the Achilles tendon.

Keywords: Achilles tendon rupture, foot deformities, planovalgus foot, sports injury, male athletes

Streszczenie

Wprowadzenie i cel: Zerwanie ścięgna Achillesa należy do najczęstszych urazów sportowych. Celem pracy była analiza związku przyczynowo-skutkowego pomiędzy nieprawidłowościami w budowie i czynności stopy a zerwaniem ścięgna Achillesa u mężczyzn uprawiających sport. **Materiał i metody:** Przeprowadzone badanie kliniczne obejmowało grupę 41 mężczyzn leczonych operacyjnie z powodu zerwania ścięgna Achillesa oraz kontrolną grupę 40 mężczyzn, którzy spełniali te same kryteria włączenia do badania z wyjątkiem przebytego zerwania ścięgna. Każdy uczestnik przechodził kolejno badanie ortopedyczne, badanie radiologiczne stóp na stojąco oraz badanie na platformie chodu. Końcowym etapem było badanie doświadczalne z zakresu biomechaniki układu mięśniowo-szkieletowego kończyn dolnych, z oceną sił powstających w ścięgnie Achillesa, a także analiza statystyczna uzyskanych wyników. **Wyniki:** Z badania radiologicznego stóp na stojąco oraz badania na platformie chodu wynika, iż stopy osób w grupie badanej miały znacznie więcej odchyleń od normy w porównaniu z grupą kontrolną. W badaniu radiologicznym zaobserwowano znacznie częstsze występowanie w tej grupie cech budowy stopy płasko-koślawej jedno- lub obustronnie. Znacznie częściej w grupie badanej przeciążane było przodostopie oraz stwierdzano ustawienie stopy w nadmiernym odwiedzeniu, co jest charakterystyczne dla stopy płasko-koślawej. Wyniki badania doświadczalnego wskazują, że wraz ze wzrostem obciążania przodostopia wzrasta siła przenoszona przez ścięgno Achillesa. **Wnioski:** Zniekształcenie płasko-koślawe stóp u mężczyzn uprawiających sport, którzy zerwali ścięgno Achillesa w przeszłości, jest najczęściej obserwowaną wadą stóp i znacznie zwiększa siły przenoszone przez ścięgno.

Słowa kluczowe: zerwanie ścięgna Achillesa, zniekształcenia stopy, stopa płasko-koślawa, uraz sportowy, mężczyźni uprawiający sport

INTRODUCTION

The so-called "healthy lifestyle" has gained popularity in recent years. More and more people, in addition to taking care of proper nutrition, undertake various sports disciplines. With the increased interest in physical activity, the number of accompanying injuries has also grown. One of the most common injuries is Achilles tendon (AT) rupture (ATR). Various sources indicate that it may affect from seven to even 40 people per 100,000 per year(1–3). ATR mainly affects men in the 3rd and 4th decades of life. Most often, this type of injury occurs during sports activities involving, in particular, the lower limbs, e.g. running, football, basketball, volleyball, tennis, etc.(1–3). According to the literature, 48% of AT injuries in the United States occur while playing basketball, while in Europe football is the most common cause of tendon rupture(3,4). Surgical treatment, followed by a period of convalescence, leads to the exclusion of patients not only from physical activity but also often from professional life for a period of 6–12 months(5). There are many factors contributing to tendon rupture, both external and internal. Despite many years of research, there is no consensus on which of them plays the most important role. Most often, the aetiology of this type of injury is complex. The literature abounds in publications emphasising the importance of such factors as age, sex, body weight, blood group, genetic factors, chronic steroid therapy, diabetes, heavy smoking, training errors, and many others(3,6,7). Possible intrinsic factors leading to ATR also include disorders in the structure and function of the foot, but there are few studies discussing this problem in a broader aspect.

AIM OF THE STUDY

The aim of the study was to analyse the cause-effect correlation between ATR and the occurrence of disorders in the structure and function of the foot in men practising sports.

MATERIALS AND METHODS

In the years 2014–2018, at the Department of Traumatology and Orthopaedics, a total of 239 patients, including 38 women and 201 men, underwent surgical treatment due to ATR. The following criteria for study inclusion were introduced: informed consent to participate in the study, age 20–49 years, male gender, ATR during sports activities, regular physical activity before tendon injury (minimum 150 minutes a week, i.e. three workouts of 50 minutes or five workouts of 30 minutes), no chronic comorbidities, nonsmoker, body mass index (BMI) <35. Taking into account the above criteria, the study group consisted of 41 men and the control group of 40 men (comprising volunteers who met the same inclusion criteria as in the study group, except for a history of ATR).

The study was approved by the Bioethics Committee (Resolution No. 43/WIM/2017 of 9 August 2017).

The participants in both groups underwent radiographic examination of the feet in a standing position, in two views: anterior-posterior (AP) and lateral. The following radiographic parameters were analysed using the Alteris-Nawigator software: talometatarsal-1 angle on the AP and lateral view radiographs, talonavicular coverage angle on the AP view radiograph, calcaneal peach angle on the radiograph in the lateral view, and talocalcaneal angle in the lateral view radiograph. X-ray assessment was performed to assess the structure of the foot and to detect possible disorders.

Each study participant underwent static and dynamic examinations of the feet on a platform of ground reaction forces with a passive path (Mata BASE). The device shows precisely which part of the foot transfers loads to the ground while standing as well as while walking. The mat is connected to a computer, so the test results can be analysed on an ongoing basis using the FreeSTEP software.

An experimental study was carried out in the field of biomechanics of the musculoskeletal system of the lower limbs to assess the forces arising in AT for various variants of foot positioning and various schemes of pressure distribution of ground reaction forces on the surface of the foot. The study was carried out using the OpenSim software. As input data for the models, the results of measurements of pressure distribution on the foot during loading (testing on the ground reaction forces platform) were used. The results obtained in numerical simulations made it possible to assess the impact of the foot structure, the arrangement of the foot segments, and the distribution of ground reaction forces on the loads arising in AT. On this basis, it was possible to draw conclusions about overloads in the tendon, as well as to assess the risk of its possible damage depending on the position of the foot. The OpenSim software uses a full-body model consisting of 69 rigid bodies representing different segments of the human body (bones), which are defined by mass and main axes of inertia applied at the centre of mass of the segment. The joints were represented by kinematic pairs, with the number of degrees of freedom depending on the anatomical conditions of the joints. The muscular system of the human body was modelled using 1,000 active force elements representing muscle fibres. The line of action of individual muscles was defined using the initial and final attachments, or intermediate points.

Statistical analysis of all obtained results was carried out using the Statistica 13 program. The non-parametric Mann–Whitney *U* test was used to analyse the homogeneity of the study and control groups in terms of age and BMI, and the Student's *t*-test in terms of height and weight. The chi-square test was used to compare the prevalence of abnormal values of individual angles in the foot between the groups. Comparison of the mean values of all angles, except the

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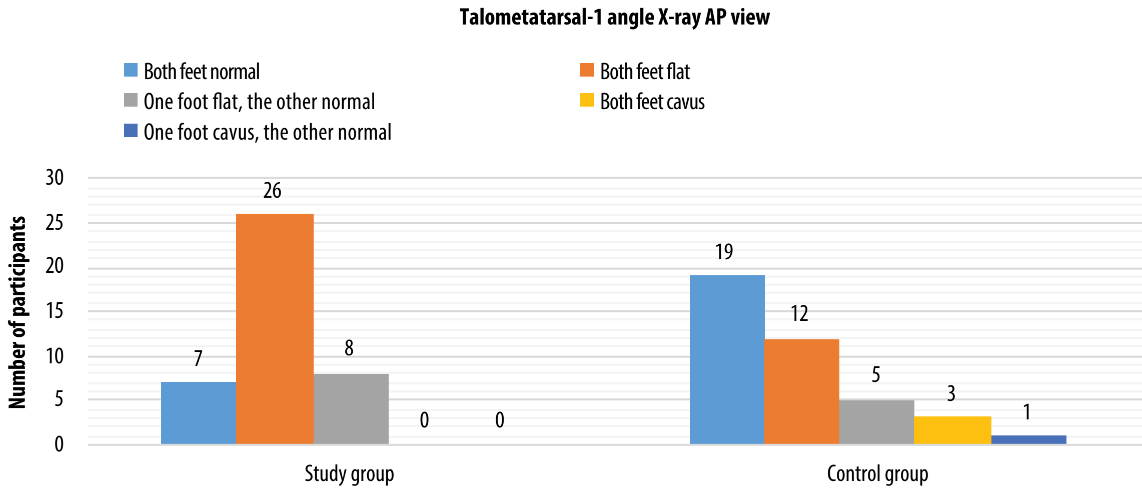

Fig. 1. Distribution of abnormalities in the foot structure in the study group and the control group based on the talometatarsal-1 angle on plain radiograph AP view

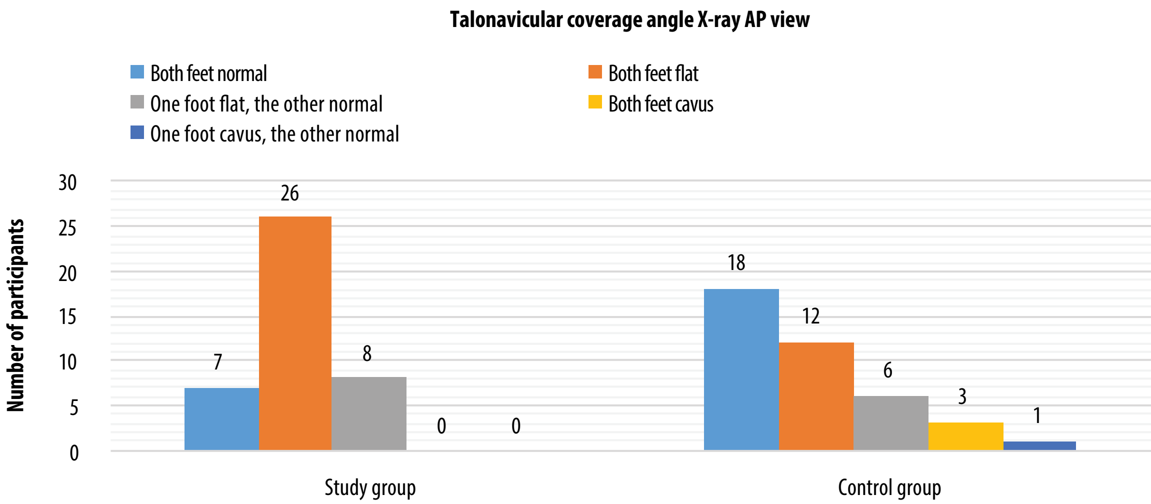

Fig. 2. Distribution of abnormalities in the foot structure in the study group and the control group based on the talonavicular coverage angle on plain radiograph AP view

talometatarsal-1 angle in the AP view, which was not calculated in numerical values, was made using the Mann–Whitney *U* test. The distribution of irregularities in the loading of the right and left feet, as well as the forefoot and hindfoot, in the study group and the control group, was determined using the chi-square test. The level of statistical significance of 0.05 was assumed in all tests.

RESULTS

Radiographic examination

Among the study participants with ATR, abnormal talometatarsal-1 angle (a component of planovalgus foot) on the radiographs in the AP view was significantly more common than in the control group (Fig. 1). The difference between the groups was statistically significant ($p = 0.0034$).

In the study group, abnormal talonavicular coverage angle (a component of planovalgus foot) on the radiographs in the AP view was also significantly more common than in the control group (Fig. 2). The difference between the groups was statistically significant ($p = 0.0065$).

In the study group, abnormal talometatarsal-1 angle on the radiographs in the lateral view (a component of planovalgus foot) was significantly more frequent than in the control group (Fig. 3). The difference between the groups was also statistically significant ($p < 0.0001$).

In the study group, abnormal calcaneal peach angle (a component of planovalgus foot) on the radiographs in the lateral view was significantly more frequent than in the control group (Fig. 4). The difference between the groups was also statistically significant ($p = 0.0027$).

In the study group, abnormal talocalcaneal angle (a component of planovalgus foot) on the radiographs in the lateral

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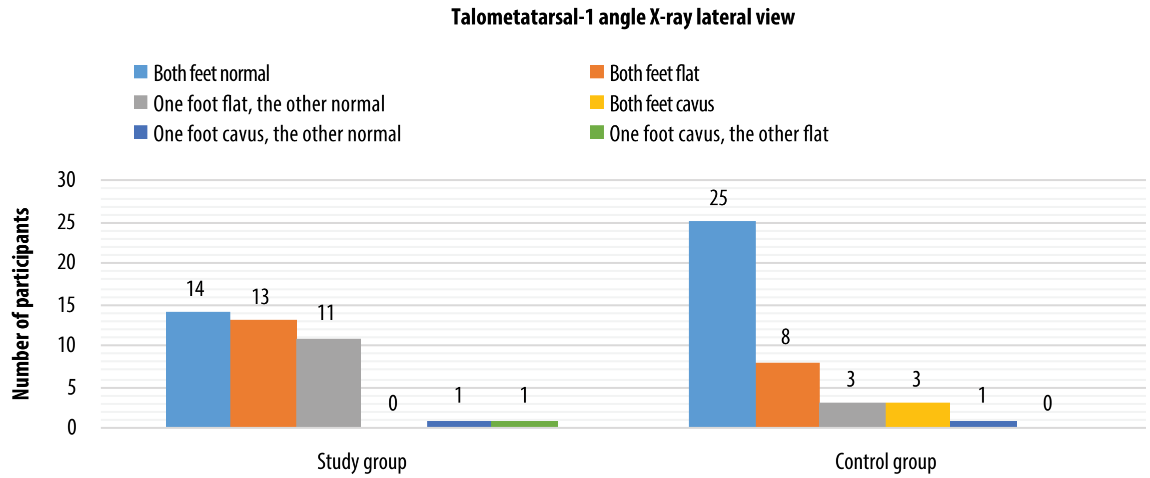

Fig. 3. Distribution of abnormalities in the foot structure in the study group and the control group based on the talometatarsal-1 angle on plain radiograph lateral view

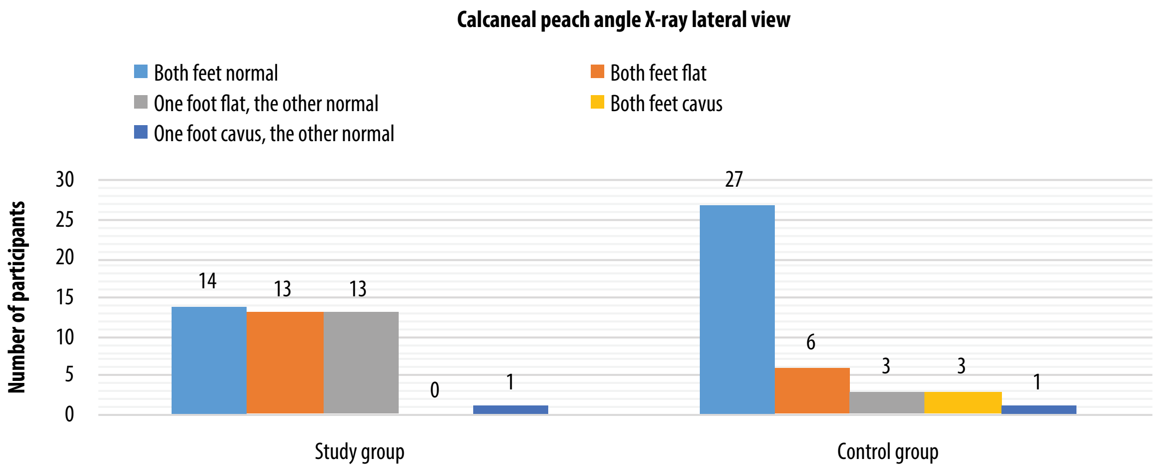

Fig. 4. Distribution of abnormalities in the foot structure in the study group and the control group based on the calcaneal peach angle on plain radiograph lateral view

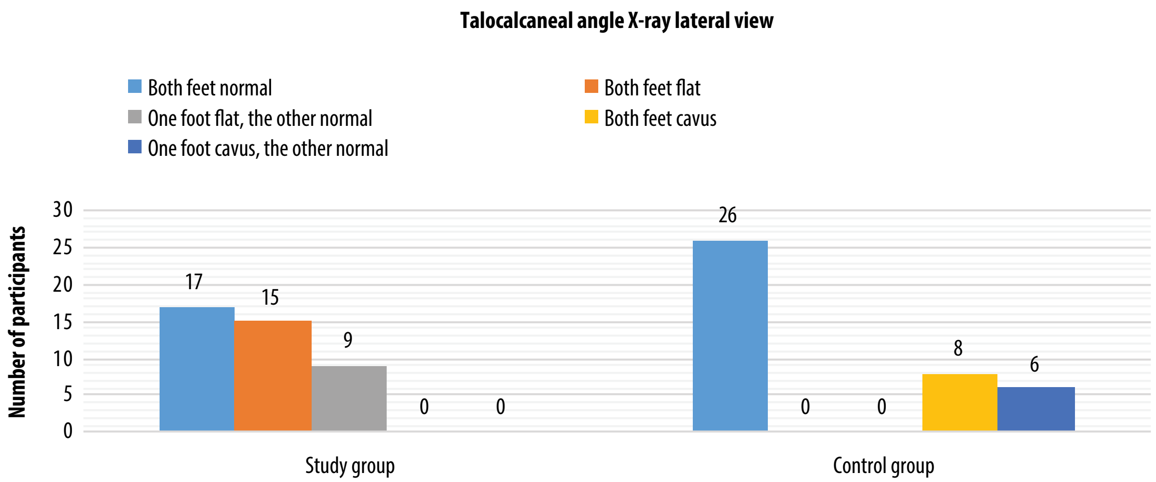

Fig. 5. Distribution of abnormalities in the foot structure in the study group and the control group based on the talocalcaneal angle on plain radiograph lateral view

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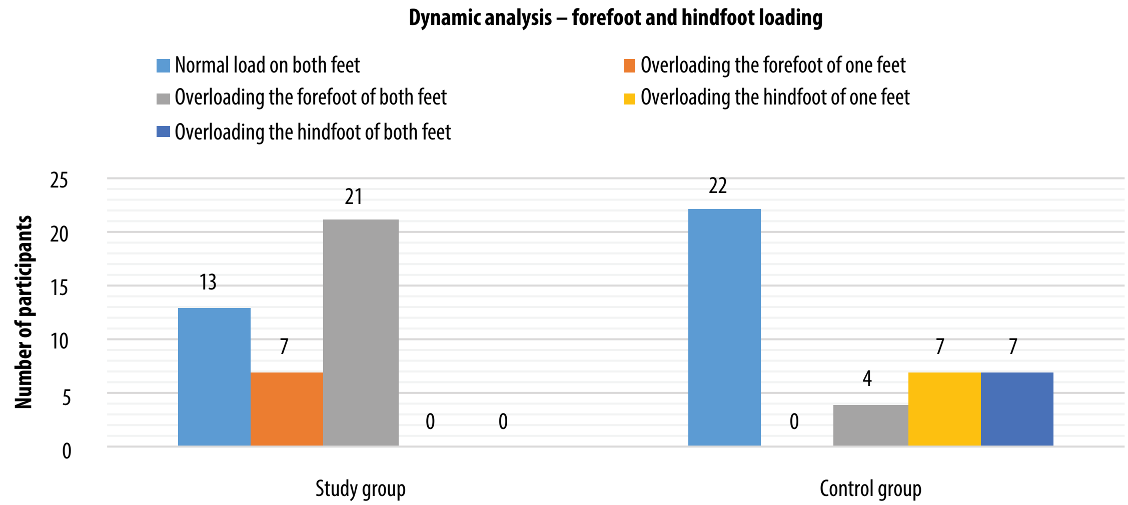

Fig. 6. Load distribution between the forefoot and hindfoot of one foot or both feet during walking in the study group and control group

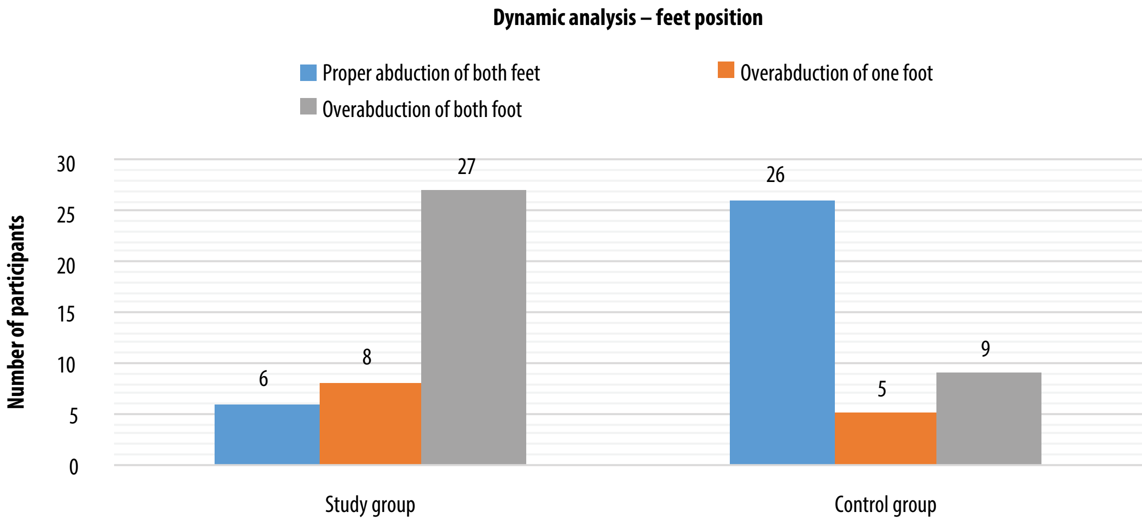

Fig. 7. Method of positioning the feet during walking in the study group and control group

view was significantly more frequent than in the control group (Fig. 5). The difference between the groups was statistically significant ($p = 0.0338$).

Platform of ground reaction forces with a passive path (Mata BASE)

The dynamic analysis based on the assessment of the load on the forefoot and hindfoot during walking in the ATR and control groups showed that significantly more participants in the ATR group overloaded the forefoot of both feet compared to the control group, in which most individuals loaded both feet within normal limits (Fig. 6). The difference between the groups was statistically significant ($p < 0.0001$).

A similar situation was noted with regard to foot abduction during walking. Significantly more participants in the study group excessively abducted both feet compared to the control group (Fig. 7). The difference between the groups was statistically significant ($p < 0.0001$).

Experimental part of the study

The experimental study shows that the forces transmitted by AT increase along with an increase in the load on the forefoot, an increase in the BMI index, an increase in the load on the medial part of the forefoot (Fig. 8), and when the lower limb is externally rotated to 12 degrees and the foot is in significant pronation of 12 degrees (marked 10 on the chart in Fig. 9).

DISCUSSION

Any deviation in the structure of the musculoskeletal system affecting both professional and recreational athletes can exclude them forever or for a long time both from

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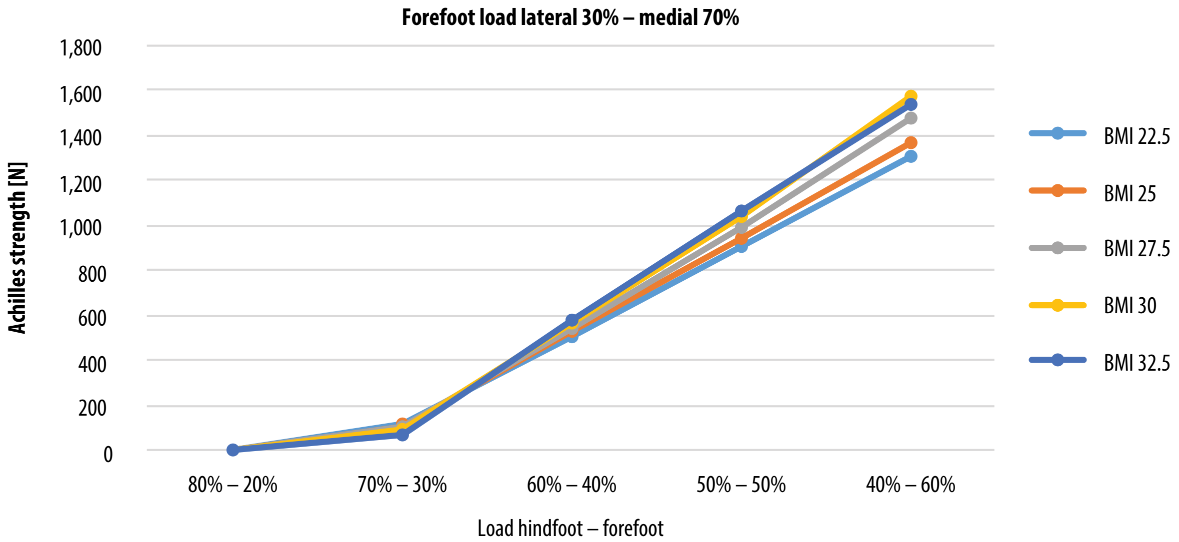

Fig. 8. Values of the force transmitted by the Achilles tendon depending on the hindfoot-forefoot load pattern and BMI for the forefoot load pattern, lateral 30% – medial 70%

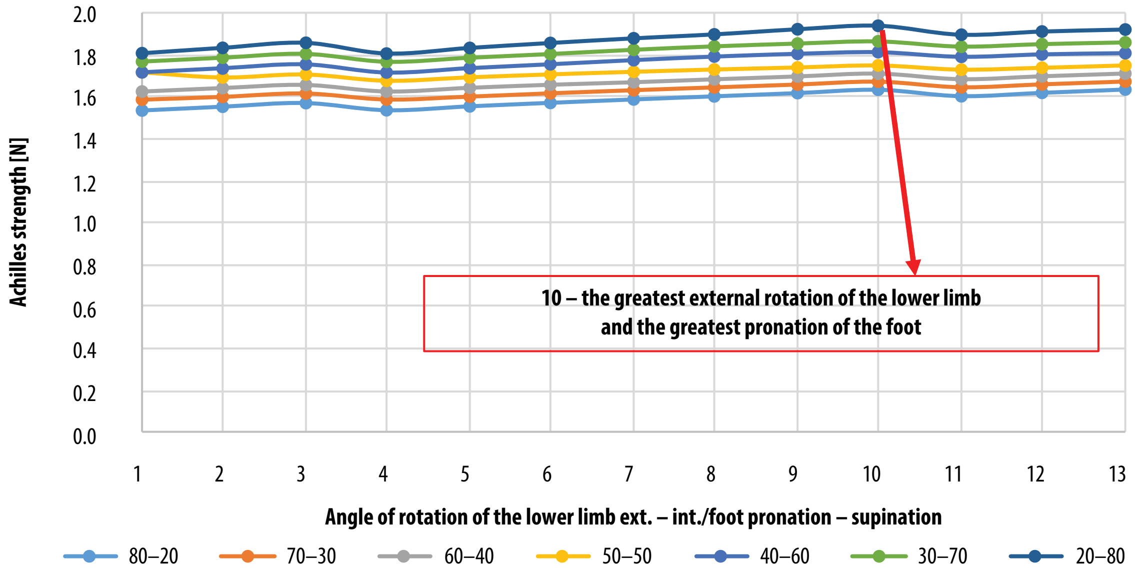

Fig. 9. Values of forces transmitted by the Achilles tendon depending on the rotation of the lower limb relative to the long axis of the limb and the position of the foot (pronation/supination of the foot) for various patterns of loading the lateral-medial part of the forefoot

professional and everyday life activities. ATR is one of the most common sports injuries. Despite this, its aetiology is still unknown. The causes are attributed to both internal and external factors. In the literature on this topic, the majority of publications attempt to explain the role of internal factors. Attention is drawn to changes occurring in the structure of AT itself and causing its rupture, including disorders in the structure of collagen, chronic ischaemia, genetic factors, sex, and body weight. The factors listed above are mentioned by Lemme et al.[(3)], Yammine et al.[(7)], Claessen et al.[(8)], and other authors. Not only these internal, but also external factors contribute to ATR, as described in the research papers by Wertz et al.[(9)], Alves et al.[(10)], and Teng et al.[(11)]. The most frequently discussed topics related to external factors include degenerative changes in the tendon as a result of oral drug therapy (fluoroquinolones, anti-diabetic agents, steroids) and topical drug treatment (steroids), smoking, and training errors.

Our study was aimed at elucidating the possible internal causes of ATR in young men active in sports involving the lower limbs. The study involved healthy men, in whom the above-mentioned external and internal factors had been excluded, yet they had a positive history of ATR. Therefore, the presented study was focused on the assessment of foot structure in young men actively practising sports.

Based on the radiographic examination, it was found that the majority of subjects in the study group had features of planovalgus foot, which led to the conclusion that this

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might be a factor increasing the risk of ATR. No subjects in the study group had features of cavus foot, which occurs in 10.5–25% of the adult population(12). Despite this, Wertz in his review, in which he collected 22 articles on AT, mentions cavus foot as a causative factor the rupture of AT, among other contributing factors(9). Young and Maffulli present similar conclusions in their study(13). Ryan et al., on the other hand, after examining a group of runners, found that athletes with flat feet were more prone to ATR, which is consistent with our results(14). Excessive pronation of the foot (which is a component of flat foot) as the cause of ATR is also mentioned in the study by Lee et al. and Hess(15,16). In the literature, one can find articles about the impact of the position of the forefoot and hindfoot on the forces transmitted by AT, affecting the risk of tendon rupture. In our analysis, 80.5% of the men in the study group had forefoot abduction, and 53.6% of the participants had hindfoot valgus on the surgical side. Paavola mentions forefoot abduction and hindfoot valgus as the disorders that may contribute to ATR(17). Ryan et al. point out the fact that in the group of runners with ATR, the hindfoot valgus is higher than in the control group(14). Lee et al. observed in their study that excessive pronation of the forefoot (which is also associated with abduction of the forefoot) in participants with flat feet causes additional load on AT, while increased pronation of the forefoot contributes to greater hindfoot valgus(15). Waldecker, on the other hand, argues that the varus position of the hindfoot has a greater impact on the occurrence of ATR(18). Conversely, Wolfram et al. called into question the influence of pronation or supination of the foot on the amount of force transmitted by AT in healthy adults without internal diseases(19). However, it should be taken into account that the study was conducted on a group of only 11 participants. In the above-mentioned studies, the authors failed to provide their results of plain radiograph measurements and did not calculate individual angles on the basis of which the structure of the foot could be determined. They based their conclusions mainly on clinical and podoscopic examinations, which, in our opinion, is not a fully reliable source of information. In today's era of extensive diagnostic possibilities, it is worth complementing the results of clinical examinations with appropriate imaging tests, which gives studies greater credibility.

In conclusion, there is an important point to consider. With such knowledge about the possible causes of ATR in young active people, are we able to prevent it somehow? In the literature, there is no consensus or guidelines regarding the use of various types of orthoses, including orthopaedic insoles, in the prevention of AT diseases in individuals with flat feet practising running sports. The degree of advancement of foot structure disorders varies from person to person and it has not been determined when such prophylaxis should actually be implemented. Also, there are not enough comparative studies evaluating various prevention methods, including orthopaedic insoles, as options for preventing ATR. However, it has never been proven that such prevention is ineffective. Therefore, it would certainly be useful for a patient reporting AT pain to a family doctor to have at least plain radiographs and a clinical examination of the feet. The problem is not rare, and the earlier it is detected, the more likely it will be possible to implement measures to prevent tendon rupture.

CONCLUSIONS

1. Acquired foot deformities in men who regularly practise sports contribute to ATR.
2. Planovalgus foot deformity in male athletes with a history of ruptured AT is the most common foot pathology.
3. Acquired foot deformities in male athletes with no history of ATR are rare. Normal foot structure has a protective effect on AT.
4. Planovalgus foot deformity increases the forces transmitted by AT significantly.

Conflict of interest

The authors do not report any financial or personal connections with other persons or organisations which might negatively affect the content of this publication and/or claim authorship rights to this publication.

Author contributions

Original concept of study: JG. Collection, recording and/or compilation of data: JG. Analysis and interpretation of data: JG, KK. Writing of manuscript: JG. Critical review of manuscript: KK, PC. Final approval of manuscript: KK, PC.

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