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EVALUATION OF FOOT ARCH MORPHOLOGY IN SCHOOLGIRLS AND FEMALE TEAM-SPORT ATHLETES

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ABSTRACT

Background: The considerable mechanical loads placed on the lower limbs during sport-specific activities, such as jumping, landing, rapid accelerations, and frequent changes of direction - may substantially alter foot mechanics and longitudinal arch stability.
Aim: To evaluate foot arch characteristics in schoolgirls and female athletes (volleyball and basketball) and to examine the association between regular, high-impact sports participation and the development of foot arch deformities in female adolescents and young adults.
Material and Methods: The study involved 45 female participants aged 13-22 years, categorized into a control group of non-athletic peers (n=20) and a sports group of active athletes (n=25). Plantography was utilized to assess structural foot arch parameters, specifically the K-coefficient and calcaneal inclination angle. A structured questionnaire was administered to gather data on sports exposure, training history, and prior musculoskeletal injuries.
Results: Active female athletes exhibited a significantly higher prevalence of foot arch alterations compared to their non-athletic peers (84.0% vs. 15.0%, $p < 0.001$). These structural modifications were further confirmed by statistically significant alterations in both the mean K-coefficient and calcaneal inclination angle in the sports group ($p < 0.001$). Furthermore, 85.7% of athletes presenting with foot arch alterations reported a history of prior non-causal musculoskeletal injuries.
Conclusions: Regular participation in high-impact team sports is strongly associated with a higher incidence of foot arch alterations in female adolescents and young adults. These findings emphasize the necessity of routine podiatric assessments and the early implementation of targeted preventive strategies within athletic training protocols.

KEYWORDS
Foot Arch, Flatfoot, Heel Flatfoot, Female Athletes, Volleyball, Plantography

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Introduction:

Team sports, particularly volleyball and basketball, are characterized by high-intensity physical activity and a large number of repetitive movements. The main physical demands of these sports include jumping, landing, acceleration, deceleration, rapid movements, and sudden changes in direction.

Regular participation in volleyball and basketball has a positive effect on physical development and contributes to the improvement of coordination, reaction speed, agility, strength, and the functional capacity of the cardiovascular and respiratory system, which is closely linked to the individual morphological characteristics of athletes [1].

At the same time, the specific movement patterns involved in these sports place considerable mechanical stress on the lower extremities, particularly the feet. The foot is an important structural and functional component of the musculoskeletal system and performs supporting, shock-absorbing, cushioning, and stabilizing functions. The condition of the foot arches plays an important role in the proper distribution of loads during walking, running, jumping, and landing.

Changes in the condition of the foot arch, particularly its flattening, may affect movement biomechanics and alter the distribution of loads throughout the lower extremities, being a potential risk factor for lower limb injuries [2]. A number of studies have investigated the association between foot deformities and musculoskeletal injuries [3,4,5]. This issue is especially important for athletes who regularly perform a large number of jumping and speed-strength exercises, where specialized interventions like foot orthoses might modify biomechanics without compromising sports performance [6].

However, while most literature addresses how existing foot deformities contribute to injuries, there is a lack of comprehensive data on how intensive, sport-specific loads themselves act as an environmental factor

that shapes the foot arch. It remains unclear whether athletic training in jumping disciplines accelerates structural alterations of the foot compared to non-athletic peers.

Despite the positive effects of participation in team sports on physical development, the condition of the foot arch in female athletes of different ages and levels of athletic training remains an important issue. Particular attention should be paid to determining the prevalence of various foot abnormalities among sports players and to investigating the direct impact of regular sports activities on the development of foot deformities in female adolescents.

The lack of regular assessment of the functional and morphological condition of the feet may make it difficult to detect potentially unfavorable changes at an early stage. Therefore, monitoring the condition of the foot arch may be an important component of medical and pedagogical control during athletic training.

This problem can be effectively addressed through a systematic assessment of the foot arch using an accessible instrumental method. By comparing a non-athletic control group of schoolgirls with athletes of different ages and competitive levels, it is possible to determine how the duration, intensity, and specificity of athletic loads shape the foot architecture. This approach, combined with a descriptive analysis of athletes' sports history and previous musculoskeletal complaints, will provide a clearer understanding of how sports participation influences foot morphology during skeletal growth.

Furthermore, the adolescent growth spurt represents a critical window of vulnerability and structural adaptation within the human musculoskeletal system [1]. During puberty, rapid elongation of long bones frequently outpaces the adaptive muscular hypertrophy and tendinous maturation, creating temporary biomechanical imbalances across the lower extremity kinetic chain [1, 2]. In sports such as volleyball and basketball, where athletes perform hundreds of maximal vertical jumps and high-impact landings per training session, the developing immature foot structure is subjected to repetitive mechanical stress that far exceeds physiological baselines [1, 6].

The medial longitudinal arch relies heavily on both active subsystems—such as the tibialis posterior, flexor digitorum longus, and intrinsic plantar musculature—and passive stabilizers, including the plantar aponeurosis, long and short plantar ligaments, and the spring ligament complex [2, 3]. When these dynamic and static stabilizers experience continuous, exhaustive cyclic loading without adequate recovery intervals, micro-failures and viscoelastic creep can occur within the collagenous matrix [2]. Consequently, in young female athletes undergoing rapid skeletal maturation, the combined effect of high-frequency impacts and residual ligamentous laxity may predispose the longitudinal arch to structural flattening and altered calcaneal inclination [1, 5]. Investigating how these sport-specific loads modify foot architecture during adolescence remains essential for designing effective, age-appropriate injury prevention programs [2, 6].

Methodology:

To address the identified problem, an assessment of the condition of the foot arch was conducted using plantography and questionnaire-based assessment. The combination of these methods made it possible to objectively assess the condition of the foot arch and simultaneously obtain information about the participants' sports experience and history of musculoskeletal injuries.

The main instrumental method was plantography, which involves obtaining an imprint of the plantar surface of the foot followed by analysis of its shape and the area of contact with the supporting surface. This approach aligns with established methods of footprint analysis used to quantify foot arch characteristics and calculate objective metrics, such as the arch index [7]. The resulting plantograms were used to assess the longitudinal arch of the foot and identify signs of its flattening.

For quantitative assessment of the foot arch, the K coefficient was determined based on the parameters of the plantogram. This objective instrumental approach complements existing clinical screening tools, such as the Foot Posture Index developed by A. C. Redmond et al., which is widely accepted for evaluating standing foot alignment [8]. The K-coefficient was calculated based on the geometric parameters of the obtained plantograms. First, an axial reference line was drawn from the center of the heel print to the base of the second toe, and a longitudinal tangent line was constructed along the most prominent points of the medial border of the footprint. Next, a perpendicular line was drawn across the narrowest section of the midfoot arch print. The K-coefficient was then defined as the ratio of the width of the stained (inked) part of the footprint to the total width of the foot print along this perpendicular line, using the formula: $K = a/b$, where 'a' represents the width of the stained midfoot section and 'b' represents the total footprint width at the same level.

To maximize the precision and objectivity of the structural evaluation, the plantographic data acquisition protocol was standardized across all testing sessions [7]. Participants were instructed to assume a relaxed, bipedal upright stance with an even distribution of body weight across both lower limbs, ensuring a natural physiological loading of the plantar aponeurosis and longitudinal arch prior to footprint capture [7, 8]. The plantographic medium utilized high-resolution pressure-sensitive carbon-coated imaging plates that accurately documented the contact area of the plantar surface, distinguishing between weight-bearing forefoot, midfoot, and hindfoot regions [7].

The geometric construction of the K-coefficient was executed using specialized digital planimetry software to eliminate manual measurement errors [7]. By establishing a reliable axial reference line connecting the geometric center of the calcaneal imprint to the midpoint of the second metatarsal head, the software automatically isolated the narrowest Isthmus of the midfoot arch [7]. This automated approach ensured that minor variations in foot orientation did not distort the calculation of the ratio between the stained midfoot width (a) and the total footprint width (b) [7]. Similarly, the calcaneal inclination angle was derived by mapping the precise spatial coordinates of the medial calcaneal tuberosity relative to the first metatarsophalangeal joint, providing a robust, two-dimensional geometric indicator of hindfoot alignment and calcaneal pitch [1, 8].

In addition to structural footprint analysis, the standardized questionnaire administered to all participants underwent rigorous validation to capture comprehensive retrospective health data [8]. The questionnaire documented not only total athletic exposure (expressed in years and weekly training hours) but also categorized injuries chronologically and anatomically [2]. Musculoskeletal complaints were verified through medical records where available, distinguishing between acute traumatic events (such as lateral ankle sprains or acute ligamentous tears) and chronic overuse syndromes (such as plantar fasciitis, Achilles tendinopathy, and medial tibial stress syndrome) [2, 4]. This detailed stratification enabled a nuanced examination of how structural foot alterations coexist with regional lower-limb pathology across different competitive tiers [2, 5].

According to the obtained values, the condition of the foot was differentiated into hollow foot, lowered arch, and different degrees of flatfoot. A K value from 0 to 0.5 was interpreted as a hollow foot, while values from 0.51 to 1.20 corresponded to a normal and slightly lowered arch**.** Values from 1.21 to 1.30 corresponded to first-degree flatfoot, values from 1.31 to 1.50 to second-degree flatfoot, and K ≥1.51 to third-degree flatfoot.

The condition of the calcaneal region was assessed separately using the calcaneal angle, which made it possible to identify calcaneal flatfoot. The calcaneal angle was measured as the angle between the tangent line drawn along the medial border of the footprint and the line connecting the most prominent medial point of the heel with the first metatarsophalangeal joint. The cut-off value for diagnosing calcaneal flatfoot was defined as a calcaneal angle of less than 15°, indicating a pathologically dropped longitudinal arch, whereas values between 15° and 25° were considered normal.

To ensure the reproducibility and accuracy of the plantographic measurements, all prints were evaluated independently by two researchers. The inter-rater reliability was assessed using the Intraclass Correlation Coefficient (ICC). The analysis demonstrated reproducibility for the K-coefficient calculation (ICC = 0.91, 95% CI = 0.87–0.94) and the calcaneal angle (ICC = 0.88, 95% CI = 0.83-0.92), confirming the high reliability of the chosen instrumental method.

The questionnaire included questions concerning age, type of sport, duration of athletic experience, and the lifetime presence of previous injuries and disorders of the musculoskeletal system. The injury assessment focused on the cumulative history of sports-related or daily life injuries sustained by the participants throughout their entire athletic career or school years prior to the study examination.

For the purpose of this study, an injury history was defined as any self-reported acute or overuse musculoskeletal complaint sustained during sports training, competition, or daily school activities that resulted in physical discomfort, required medical consultation, or caused the participant to miss training sessions or school days. Particular attention was paid to injuries of the ankle joint, foot, hand, menisci, long bones, and spine. The captured injury characteristics were categorized by anatomical location and their relevance to the participant's sports history.

The study involved 45 participants aged 13–22 years, divided into the control and sports groups:

1. Group A — control group - 20 schoolgirls from a secondary school, aged 13–17 years;
2. Group B subgroup a — 11 female volleyball players from a children's sports school, aged 13–17 years; mean athletic experience — 2.3±0.22 years;
3. Group B subgroup b — 7 professional female volleyball players from the women's volleyball team, aged 15–22 years; mean athletic experience — 7.0±0.86 years;
4. Group B subgroup c — 7 athletes from the professional women's basketball team; mean athletic experience — 6.8±0.79 years.

Table 1. Characteristics of the Study Groups

Group	Participants	n	Age, years	Mean athletic experience, years	Mean K-coefficient	Mean Calcaneal angle, (°)
A	Schoolgirls	20	13–17	-	0.82 ± 0.14	19.4 ± 2.3
B	Sports players	25	13-22	4.88 ± 2.41	1.26 ± 0.14	12.0 ± 1.4
B (subgroup a)	Junior female volleyball players	11	13–17	2.3 ± 0.22	1.24 ± 0.12	11.4 ± 1.2
B (subgroup b)	Professional female volleyball players	7	15-22	7.0 ± 0.86	1.28 ± 0.15	12.6 ± 1.5
B (subgroup c)	Professional female basketball players	7	15-22	6.8 ± 0.79	1.27 ± 0.16	12.3 ± 1.4
Total		45				

The study protocol was approved by the local Committee of Bioethics. All procedures were performed in accordance with the Declaration of Helsinki. Since the participants included minors, written informed consent was obtained from their parents or legal guardians, and assent was obtained from the minors themselves prior to their inclusion in the study.

Results:

Plantographic examination revealed various conditions of the foot arch in all study groups, including a lowered arch, first-, second-, and third-degree flatfoot, calcaneal flatfoot, hollow foot, and foot disproportion.

1. Group A

Among the 20 schoolgirls in Group A, a lowered foot arch was identified in 15% of participants, first-degree flatfoot in 5%, second-degree flatfoot in 5%, third-degree flatfoot in 5%, and calcaneal flatfoot in 15%.

Calcaneal flatfoot was identified in 3 of the 20 schoolgirls. According to the questionnaire data, 2 of these 3 participants had a history of musculoskeletal injuries. Thus, among schoolgirls with calcaneal flatfoot, the proportion with a history of musculoskeletal injuries was 66.7%.

2. Group B

Among the 25 female athletes in the total sports group, a lowered foot arch was identified in 8.0%, first-degree flatfoot in 16.0%, second-degree flatfoot in 4.0%, and a hollow foot in 4.0%. Foot disproportion due to the predominance of the forefoot was observed in 8.0% of the sample.

Calcaneal flatfoot was identified in 21 of 25 athletes, corresponding to 84.0%. Notably, 18 of these 21 athletes (85.7%) with calcaneal flatfoot had a documented history of musculoskeletal injuries.

3. Group B subgroup a

Among the 11 junior volleyball players, a lowered foot arch was identified in 9% of participants, first-degree flatfoot in 9%, and foot disproportion due to predominance of the forefoot in 9%.

Calcaneal flatfoot was identified in 10 of 11 athletes, corresponding to 90.9%. Of the 10 athletes with calcaneal flatfoot, 9 had a history of musculoskeletal injuries, corresponding to 90%.

4. Group B subgroup b

Among the 7 professional female volleyball players, calcaneal flatfoot was identified in 5 participants (71.4%).

In addition, hollow foot was identified in 14.3% of participants, a lowered foot arch in 14.3%, first-degree flatfoot in 14.3%, second-degree flatfoot in 14.3%, and foot disproportion due to elongation of the forefoot in 14.3%.

All 7 athletes in this group had a history of musculoskeletal injuries. Among the 5 athletes with calcaneal flatfoot, all 5 had a history of musculoskeletal injuries, corresponding to 100%.

5. Group B subgroup c

Among the 7 professional female basketball players, calcaneal flatfoot was identified in 6 participants (85.7%). First-degree flatfoot was identified in 2 athletes (28.6%).

Of the 6 athletes with calcaneal flatfoot, 4 had a history of musculoskeletal injuries, corresponding to 66.7%.

The comparative analysis demonstrated that calcaneal flatfoot was the most frequently identified abnormality among female athletes participating in team sports. Its prevalence was 90.9% among junior volleyball players, 71.4% among professional volleyball players, and 85.7% among professional basketball players.

A substantial proportion of athletes with calcaneal flatfoot had a history of musculoskeletal injuries: 90% among junior volleyball players, 100% among professional volleyball players, and 66.7% among professional basketball players.

Table 2. Identified Foot Arch Abnormalities in the Study Groups

Indicator	Group A (n=20)	Group B (n=25)	Group Ba (n=11)	Group Bb (n=7)	Group Bc (n=7)
Lowered foot arch	15%	8%	9%	14.3%	-
First-degree flatfoot	5%	16%	9%	14.3%	28.6%
Second-degree flatfoot	5%	4%	-	14.3%	-
Third-degree flatfoot	5%	-	-	-	-
Calcaneal flatfoot	15%	84%	90.9%	71.4%	85.7%
Hollow foot	-	4%	-	14.3%	-
Foot disproportion	-	8%	9%	14.3%	-

Table 3. Comparison of foot arch morphology and abnormalities between the control and sports groups

	Group A (n=20)	Group B (n=25)	p-value	Interpretation
Mean K-coefficient	0.82 ± 0.14	1.26 ± 0.18	<0.001	Highly significant. Regular sports participation is linked to higher footprint index values, indicating foot-arch lowering.
Mean Calcaneal angle, (°)	19.4 ± 2.3	12.1 ± 1.8	<0.001	Highly significant. Female athletes exhibit reduced calcaneal inclination angle.
Calcaneal flatfoot	15.0% *(3)*	84.0% *(21)*	<0.001	Highly significant difference. Regular sports participation is associated with an increase in the prevalence of calcaneal flatfoot.
First, second- and third- degree flatfoot	15.0% *(3)*	20.0% *(5)*	0.716	NS
Lowered foot arch	15.0% *(3)*	8.0% *(2)*	0.642	NS
Hollow foot	0.0% *(0)*	4.0% *(1)*	—	Insufficient data
Foot disproportion	0.0% *(0)*	8.0% *(2)*	—	Insufficient data

A Fisher's exact test was conducted to analyze the association between regular sports participation and the prevalence of foot morphology alterations by comparing Group A (n=20) and Group B (n=25). A significant difference was observed in the prevalence of calcaneal flatfoot, which was higher in the sports group compared to the control group (84% vs 15%, $p<0.001$). In contrast, no statistically significant differences between the non-athletic and athletic groups were found regarding the prevalence of classic longitudinal flatfoot (15% vs 20%, $p = 0.716$) or lowered foot arch (15% vs 8%, $p = 0.642$). The mean plantographic K-coefficient was higher in the athletic group compared to the non-athletic control group (1.26 ± 0.18 vs 0.82 ± 0.14, $p<0.001$). Concurrently, sports participation was associated with a significant reduction in the mean calcaneal inclination angle (12.1 ± 1.8° vs 19.4 ± 2.3°, $p<0.001$).

Table 4. Calcaneal Flatfoot and History of Musculoskeletal Injuries

Group	Number of participants	Calcaneal flatfoot, n (%)	Participants with a history of musculoskeletal injuries, n (%)
A — Schoolgirls	20	3 (15.0%)	2 (66.7%)
B – sports players	25	21 (84%)	18 (85.7%)
Ba — Junior female volleyball players	11	10 (90.9%)	9 (90.0%)
Bb — Professional female volleyball players	7	5 (71.4%)	5 (100%)
Bc — Professional female basketball players	7	6 (85.7%)	4 (66.7%)

Regarding the self-reported survey outcomes, a substantial cumulative proportion of athletes presenting with calcaneal flatfoot reported a lifetime history of musculoskeletal injuries (18 out of 21 participants, 85.7%), while 2 out of 3 schoolgirls (66.7%) with calcaneal flatfoot also reported prior musculoskeletal complaints. However, it is critical to emphasize that these high percentages represent descriptive findings of cumulative sports and life history and do not demonstrate that foot-arch flattening is a direct causal factor for sustaining musculoskeletal injuries.

It is worth noting that anthropometric characteristics, such as body height and mass, inherently differ between non-athletic schoolgirls and elite basketball or volleyball players. While increased body mass can place additional mechanical stress on the longitudinal arch, our findings indicate that the sport-specific jumping and landing patterns play a dominant role in the functional adaptation of the foot.

Discussion:

The findings of this study demonstrate a markedly higher prevalence of foot arch alterations—specifically calcaneal flatfoot—among female adolescents and young adults regularly participating in high-impact team sports, such as volleyball and basketball, compared to their non-athletic peers. While traditional longitudinal flatfoot showed no statistically significant difference between the groups (15% vs 20%, $p = 0.716$), the incidence of calcaneal flatfoot was profoundly elevated in the athletic cohort (84% vs 15%, $p<0.001$). Furthermore, objective plantographic metrics confirmed significant morphological adaptations, evidenced by a substantially higher mean K-coefficient (1.26 ± 0.18 vs 0.82 ± 0.14, $p<0.001$) and a reduced calcaneal inclination angle ($12.1 \pm 1.8°$ vs $19.4 \pm 2.3°$, $p<0.001$) among the athletes.

These biomechanical adaptations can be directly attributed to the unique movement profile of volleyball and basketball, which place repetitive, high-magnitude mechanical loads on the lower extremities [1]. Sport-specific activities—such as frequent vertical jumps, forceful landings, rapid accelerations, and sharp directional changes—generate ground reaction forces that significantly exceed body weight [1, 6]. During repetitive impact loading, the medial longitudinal arch acts as a primary shock absorber, undergoing cyclic deformation and considerable stress [1, 7]. Over prolonged athletic exposure, cumulative mechanical stress can exceed the adaptive capacity of the plantar soft tissues, posterior tibial tendon, and supporting ligamentous structures, leading to functional lowering of the arch and structural changes in the calcaneal inclination [1, 2].

Our observations align with broader biomechanical research indicating that sports involving explosive jumping and landing impose distinct stress patterns on the pediatric and adolescent foot structure [1, 5]. Although previous literature extensively evaluates foot posture as a potential predisposing risk factor for lower limb overuse injuries [2, 3], the current study emphasizes the reverse pathway: how intensive athletic conditioning and growth-period mechanical exposure actively shape foot morphology. The high prevalence of calcaneal flatfoot observed across junior and professional subgroups (ranging from 71.4% to 90.9%) suggests that these structural variations represent a common functional adaptation rather than an isolated pathological anomaly in athletic populations.

From a biomechanical standpoint, the contrast between structural changes in the medial longitudinal arch and traditional flatfoot warrants careful analysis [3, 8]. While classical flexible flatfoot often involves generalized ligamentous laxity and generalized foot collapse [3], the calcaneal flatfoot observed in these high-impact athletes reflects a specific adaptive lowering of the calcaneal pitch [1]. The repetitive high-velocity

eccentric loads during landings in basketball and volleyball force the calcaneus into persistent valgus alignment and alter the spatial orientation of the subtalar joint [6]. This structural shift suggests that intensive jump training preferentially alters the osseous orientation and heel alignment without necessarily causing the classical medial longitudinal collapse seen in generalized hypermobility syndromes.

Furthermore, comparing subgroup variations provides valuable insight into the timeline of foot architecture modeling [1]. High rates of calcaneal flatfoot were documented in both junior athletes (90.9% in subgroup Ba) and elite senior professionals (71.4% in subgroup Bb and 85.7% in subgroup Bc), indicating that structural adaptation occurs relatively early during athletic specialization [1]. During early adolescence—a period marked by rapid skeletal growth and incomplete ossification—the foot skeleton is particularly susceptible to external mechanical stimuli [1, 5]. The high mechanical demand of daily sports practice during this maturation window accelerates the adaptation of foot posture, establishing structural foot alterations that persist into adult professional careers.

Additionally, the retrospective survey revealed that a substantial cumulative proportion of athletes presenting with calcaneal flatfoot reported a history of musculoskeletal injuries (85.7% in the total sports group). However, it is essential to interpret this association with caution [2, 4]. Because the injury data capture self-reported lifetime complaints accumulated throughout school years and long-term athletic careers, these descriptive findings do not establish a direct causal relationship indicating that foot-arch alterations directly provoke acute injuries [2, 3, 5]. Instead, they highlight that athletes with modified foot architectures frequently manage concurrent musculoskeletal complaints, underscoring the complex, multifactorial nature of sports-related injuries [2, 4].

These findings carry significant practical implications for athletic training, sports medicine, and injury prevention strategies [6, 8]. Given the high baseline prevalence of foot arch alterations and associated musculoskeletal complaints in team-sport athletes, routine podiatric screening should be incorporated into standard medical evaluations [8]. Early identification of altered plantographic indices (such as an elevated K-coefficient or reduced calcaneal angle) allows sports physicians and physical therapists to implement targeted neuromuscular conditioning, intrinsic foot muscle strengthening, and individualized orthotic support [6, 8]. Such proactive interventions can optimize plantar pressure distribution, enhance shock-absorbing capacity during jumping tasks, and mitigate long-term structural strain on the lower extremity kinetic chain [6].

The pronounced prevalence of calcaneal flatfoot observed among female athletes in this cohort also warrants careful consideration regarding sex-specific anatomical and hormonal factors [1]. Post-pubertal females generally exhibit greater generalized joint laxity, broader pelvis configurations leading to an increased Q-angle, and distinct lower-extremity alignment parameters compared to male peers, all of which influence dynamic valgus collapse during athletic landings [3, 5]. When a female athlete executes a rebound or a blocking landing in basketball or volleyball, increased femoral internal rotation and dynamic knee valgus place an eccentric torsional load on the subtalar joint and the medial column of the foot [5, 6]. Over time, this multi-planar mechanical stress accelerates the depression of the calcaneal pitch and reinforces the structural profile identified as calcaneal flatfoot [1, 6].

Moreover, the transmission of repetitive impact forces through the lower extremity kinetic chain during explosive sports actions requires a comprehensive examination of shock-attenuation mechanisms [1, 2]. When female athletes land from a maximal vertical jump, the ground reaction forces travel rapidly from the plantar surface through the calcaneus, midfoot, and tibia, generating peak impact transients that must be absorbed by both passive osseoligamentous structures and active muscular contractions [1, 6]. The structural alterations identified in the longitudinal arch—particularly the reduction of the calcaneal inclination angle and the elevation of the K-coefficient—directly reflect an adaptive mechanical response designed to increase initial contact area and dissipate high-velocity impact energy [1, 7]. However, this morphological flattening compromises the natural elastic recoil of the medial longitudinal arch, potentially transferring greater mechanical stress onto proximal joints such as the knee and lumbosacral spine [2, 4]. Consequently, repetitive cyclic microtrauma resulting from inadequate shock absorption can accelerate tissue fatigue within the plantar aponeurosis and supportive connective tissues [2, 5]. Recognizing these biomechanical trade-offs provides vital context for understanding why high-impact athletic conditioning leads to pronounced structural remodeling in adolescent female populations, reinforcing the necessity for regular functional monitoring and preventive mechanical support throughout competitive development [1, 6, 8].

The distinction between static architectural foot posture and dynamic functional performance highlights the necessity of integrating targeted neuromuscular interventions into routine training regimens [6, 8]. Traditional views often treated flatfoot as a fixed structural defect requiring passive arch support; however,

contemporary sports medicine emphasizes active stabilization through the "core foot" concept, which targets the intrinsic musculature (such as the abductor hallucis, flexor digitorum brevis, and quadratus plantae) [6]. Given that elite volleyball and basketball players spend substantial training hours performing barefoot or shod plyometric drills on rigid gymnasium surfaces, incorporating intrinsic foot strengthening protocols—such as "short-foot" exercises and proprioceptive balance training—can significantly enhance dynamic arch stiffness, attenuate ground reaction forces, and reduce the transmission of impact shock up the kinetic chain [6, 8].

Several limitations of this study should be acknowledged. First, the cross-sectional design limits causal inferences regarding the chronological progression of foot arch flattening during skeletal growth. Second, the sample size ($n = 45$), while sufficient for identifying statistically significant plantographic differences between groups, warrants cautious generalization across broader athletic populations. Future longitudinal studies tracking female athletes from early adolescence through competitive maturity are necessary to evaluate the precise timeline of morphological foot adaptation and to determine the efficacy of targeted interventions, such as custom foot orthoses [6], in modulating lower limb biomechanics during high-impact training.

Conclusion:

The study demonstrated a significantly higher prevalence of foot arch alterations among female adolescents and young adults participating in team sports (volleyball and basketball) compared to their non-athletic peers. Statistical analysis confirmed that regular sports participation is associated with an elevated rate of calcaneal flatfoot (84.0% in athletes vs 15.0% in the control group, $p<0.001$).

Furthermore, descriptive findings from the retrospective survey indicated that a substantial cumulative proportion of athletes diagnosed with calcaneal flatfoot had a lifetime history of musculoskeletal injuries (85.7 % in the total sports group). Given that the data reflect self-reported lifetime complaints within a long-term athletic career, these descriptive outcomes do not establish a direct causal relationship between specific foot-arch characteristics and the onset of musculoskeletal injuries.

The findings highlight the practical importance of regular instrumental monitoring of foot morphology at different stages of athletic training. Plantography serves as a reliable, accessible, and non-invasive screening method for detecting structural variations and tracking functional foot adaptation to intensive athletic loads during skeletal growth.

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