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The Impact of Foot Arch Morphology on Risk of Overuse Injuries in Amateur Runners: A Prospective Biomechanical Study

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Abstract

The log arch structure significantly influences lower limb movement and response to repetitive stress, particularly among non-elite runners and physical activity practitioners. Current research has inadequately explored the relationship between foot structure and injury risk, as blood DNA sequencing has not definitively linked pes planus (flat foot) and pes cavus (high arch) to injury potential. This research investigates the connections between foot structure morphology, intrinsic foot muscle power, and genetic elements (SNPs) concerning repeated strain injuries through a comprehensive literature analysis. An analytical review was conducted, examining data from peer-reviewed studies sourced from Scopus, Web of Science, and PubMed. Inclusion criteria encompassed genetic, biomechanical, radiographic, and cross-sectional studies on non-elite runners, including children and adolescents. Key metrics analyzed included navicular height, arch height index, calcaneal inclination angle, and toe and MTP joint strength, all in relation to injury risk. Data were analyzed descriptively and through correlations using Pearson correlation and logistic regression models. The findings indicated that flat feet are associated with higher instances of plantar fasciitis and shin splints, while cavus feet present an increased risk for stress fractures and tendinopathies due to inadequate shock absorption. Individuals with weak intrinsic foot muscles exhibited poor arch support, heightening injury susceptibility. Notably, 137 SNPs were linked to connective tissue, neuromuscular, and inflammatory disorders affecting arch morphology, with sex and BMI identified as significant outcome factors. Arch structure and intrinsic muscle strength are critical risk factors for overuse injuries. The study emphasizes the need for injury prevention strategies that integrate biomechanical assessments, muscle strengthening, and genetic evaluations.

Keywords: *Foot Arch Morphology, Overuse Injuries, Amateur Runners, Biomechanics, Injury Prevention, Systematic Review.*

Introduction

Running has become one of the most practiced forms of exercise which provides several wellness advantages to participants. Amateur runners face substantial danger of developing overuse injuries when they participate in running activities [1, 2]. Research shows running

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injuries affecting training time for runners occur at a rate of 50% per year and these injuries primarily stem from repetitive strain on knee ankle and foot areas to the extent of 70–80% of cases [3].

Scientific studies indicate foot arch morphology exists as a natural structure with three categories high (pes cavus), normal and low (pes planus) which scientists use to analyze the risk for overuse injuries [4]. Gas absorption and load distribution functions of the medial longitudinal arch are essential for normal gait function [5]. The same factor that can modify lower limb movement patterns simultaneously raises the risk for potential injuries [6]. Stress fractures and bony injuries become more common for runners when they have high arches because they exhibit stiff lower extremities and experience higher loading rates. Plantar fasciitis and the stresses on medial tibial tissue are more likely to occur in runners who display increased foot pronation owing to low arch development [7].

The correlation between foot arch shape and overuse injuries remains vague despite available research findings. Various research investigations demonstrate substantial ties (correlation) yet other studies show no meaningful relationship (association) at all. Multiple potential sources of disagreement include diverse methodologies used during research and distinct participant groups along with testing methods employed. The research needs to integrate all available literature to understand this connection better [8].

The purpose of this systematic review involves the evaluation and merger of existing evidence regarding how foot arch form influences amateur runner susceptibility to overuse injuries. It reviews planned biomechanical investigations to find out which types of arches increase injury vulnerabilities so clinicians can develop prevention strategies and treatment plans.

Literature Review

Research has intensified focus on biomechanical along with structural factors which lead to overuse injuries because of arch morphology of the foot. Various studies have investigated the connections between foot posture alongside intrinsic muscle strength and their impact on injury risks throughout multiple population segments and athletic levels and age-related groups. The expanding research body shows that musculoskeletal injuries stem from multiple causes because they result from interactions between body position and muscular control systems and training demands and footwear conditions. Genetic research has identified hereditary factors which create a susceptibility for specific arch configurations and their associated injury patterns in people. Recent studies focusing on various dimensions of the external foot deficiency issue will be examined in this section. Investigation will encompass both morphological evaluations and functional strength measures together with injury incidence patterns and genetic predisposition facts. The existing scientific research provides the necessary basis for conducting the present investigation.

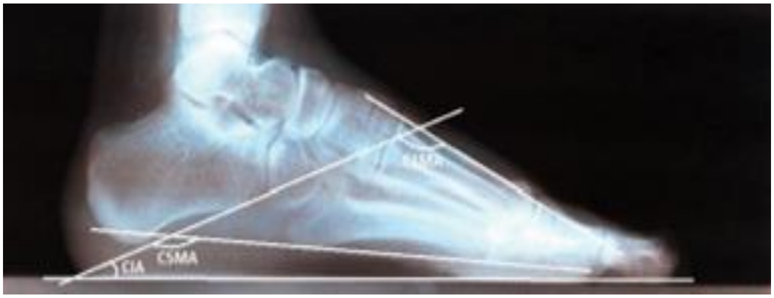
The systematic review conducted by He et al. (2025) explores foot arch morphology genetic factors which are investigated through single nucleotide polymorphism (SNP) analysis. Researchers studied 19 studies that yielded a total of 137 genetic regions called single nucleotide polymorphisms which connected to familiar musculoskeletal system genetic disorders. Flatfoot (pes planus) appeared most often with connective tissue disorders PTTD and Marfan Syndrome and EDS and researchers identified crucial SNPs that targeted collagen-related genes COL3A1, COL5A1 and examples of matrix metalloproteinases including MMP1 and MMP13. When it comes to pes cavus foot type, neuropathies and myopathies including Charcot–Marie–Tooth disease (CMT) and distal arthrogryposis (DA) syndromes primarily occur through mutations in MFN2, SIPA1L2 and MYH family proteins [9]. The Gene Ontology (GO) analysis revealed that such genetic variants strongly favored biological processes involving muscle contraction together with filament sliding behavior. Notably, only two SNPs were replicated across independent studies, emphasizing a major research gap in the genetic understanding of normal foot arch variation in the general population.

Gwani et al. (2017) studied foot arch relationships of lateral and medial along with transverse regions alongside their effects on lower extremity functioning. The analysis of right foot weight-bearing lateral bilateral radiographs was performed on seventy-six subjects where fifty-eight were men and eighteen were women. The research evaluated the morphological parameters including navicular height (NH), medial cuneiform height (MCH) and calcaneal inclination angle (CIA), and calcaneal-first metatarsal angle (C1MA) for the medial arch as well as Cuboid height (CH) and calcaneal-fifth metatarsal angle (C5MA) for the lateral arch and MCH and CH for the transverse arch. Multiple foot structure measurements showed substantial relationship levels ranging from moderate to excellent strength according to research results [10]. The correlation between CIA and C1MA ($r = –0.90$) and CIA and C5MA ($r = –0.84$) was the highest among all measurements thus suggesting medial arch geometry changes affect the structure of both transverse and lateral arches. The results from this research demonstrated that male and female participants did not show any meaningful differences concerning the foot characteristics examined during the study. The study determined that medial arch elevation can trigger compensatory changes to both lateral and transverse foot structures which proves how the foot arches work in unison to support stability and function.

Variable	**Combined Mean ± SD**	**Gender diff. p-value**	**Strongest correlation (r) with…**	**r-value**
Navicular height (NH) [cm]	2.69 ± 0.68	0.222	Medial cuneiform height (MCH)	0.77
Medial cuneiform height (MCH) [cm]	1.97 ± 0.51	0.061	NH	0.77
Calcaneal inclination angle (CIA) [°]	14.67 ± 4.70	0.736	C1MA	–0.90
C1MA [°]	142.88 ± 7.63	0.913	CIA	–0.90
Cuboid height (CH) [cm]	1.12 ± 0.33	0.971	MCH	0.56
C5MA [°]	162.75 ± 5.58	0.487	(correlation only)	—

Table. 1. Gender Comparisons for Foot Morphology Variables According To [10].

(a)



(b)

Fig.2. (a) Measurement of navicular height (NH), cuboid height (CH) and medial cuneiform height (MCH), and (b) Measurement of calcaneal inclination angle (CIA), calcaneal first metatarsal angle (CIMA) and calcaneal-fifth metatarsal angle (C5MA).

Hollander et al. (2017) conducted an epidemiological investigation on foot morphology within a group of 810 barefoot children and adolescents (11.99 ± 3.33 years with 50.1% females) after they factored out sex, BMI, side and ethnicity effects in their results. Lifetime footwear use created substantial alterations in foot shape features because participants who wore shoes their whole lives presented a diminished static Arch Height Index ($p < 0.001$) and reduced pliability ratio ($p < 0.001$) alongside a narrower hallux angle ($p = 0.001$) relative to shoes-less participants. Children who wore shoes showed statistically significant findings of shorter foot length at ages 6–10 and 14–18 and narrower feet at 6–10 years and a flatter dynamic arch index at 10–14 years ($p = 0.006$, $p = 0.010$, $p < 0.001$ and $p < 0.001$ respectively). The confounder analysis proved that BMI and sex together with foot side affected static and dynamic arch measurement results significantly (all $p < 0.01$). These research results show that kids who frequently wear shoes throughout their growth periods develop smaller medial arches and less flexible feet which could lead to increased future injury dangers alongside reduced motor function abilities [11].

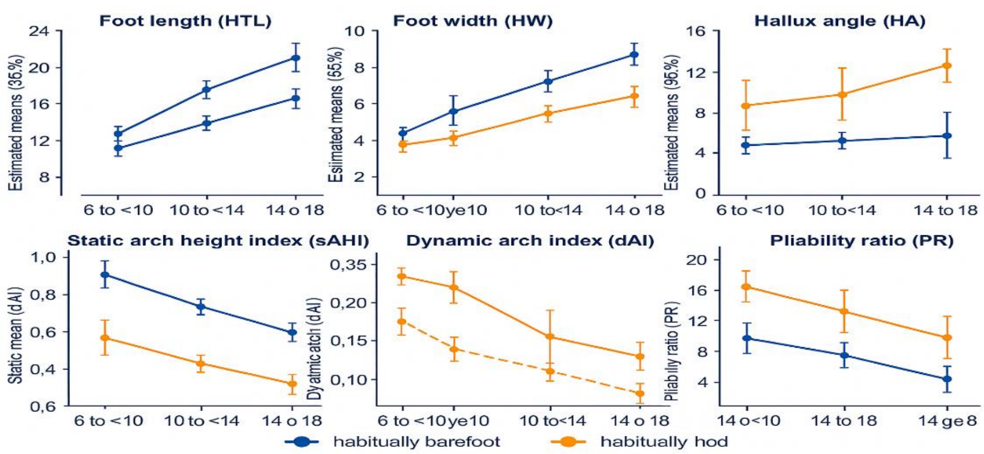


Fig.3. Marginal Effects of Habitual Barefoot Vs. Habitually Shod Children by Age According To [11].

Through their study Xiao et al. (2020) analyzed how foot morphology affects foot muscle strength testing in healthy adults who assume sitting and standing positions. The study team documented substantial changes in morphological measures between different postures because the feet compressed their arches during standing. The relationship between foot length matching the first toe flexor strength demonstrated the strongest association however foot height affecting lesser toe flexor strength showed an inverse pattern that might represent compensatory foot adjustments. Research findings showed foot width along with MTP joint strength to directly affect each other thus creating improved force generation capabilities. Multiple regression analysis proved that trunk shortening in the foot along with height variations of the navicular combined with foot width alterations significantly predicted foot muscle strength. The research findings demonstrate that foot structure and function work together while identifying particular foot shape measures which predict muscle performance results as presented in Table 2 [12].

Muscle Group	**Key Morphological Predictor**	**Relationship Type**	**Coefficient (β or r)**	**Significance (p)**
First toe flexor	Truncated foot length (sitting)	Positive	**β = 0.561**	p = 0.003
Other toes flexor	↓ Navicular height (Δ standing)	Negative	**β = –0.756**	p = 0.001
Other toes flexor	Truncated foot length (sitting)	Positive	β = 0.573	p = 0.003
MTP joint flexor strength	Foot width (sitting)	Positive	**β = 0.407**	p = 0.026
MTP joint flexor strength	Difference in foot width (sit–stand)	Negative	**β = –0.373**	p = 0.040

Table. 2. Morphological Predictors of Foot Muscle Strength According To [12].

Multiple studies show a comprehensive connection between foot structure and biomechanics and their impact on risks for running-related injuries. Peterson et al. (2022) performed a systematic review with meta-analysis that united several biomechanical and musculoskeletal factors including hip adduction angles and rearfoot eversion and arch height as contributors to RRI incidence in non-elite runners [13]. Dillon et al. (2023) confirmed excessive loading together with prior injury and abnormal muscle control as more injury-risk variables than external training load by itself [14]. Sun et al. (2022) investigated biomechanical changes between forefoot and rearfoot striking patterns which affects medial longitudinal arch movement and leads to plantar fascia tension changes that modify injury risks [15]. Fredette et al. (2022) expanded these findings by explaining that RRI risk grows increasingly high when training variables including intensity and frequency exceed reasonable levels while patients exhibit poor biomechanics [16]. The study of Yu et al. (2022) used statistical nonparametric mapping to study how both heel-to-toe drop and running speed influence limb movements and foot impact patterns while running in real-time for injury prevention purposes [17]. The authors Şahin et al. (2022) demonstrated through their study that athlete performance in balance and jumping decreased as flatfoot severity (pes planus) worsened in athletes thus showing the functional consequences of altered arch structures [18]. Plantar fasciitis in active individuals represents a strong link between flatfoot along with weakened foot functioning according to Hamstra-Wright et al. (2021) [19]. The research by Agresta et al. (2022) supports the direct application of injury paradigms to footwear creation through individualized arch-type specific footwear which may help prevent RRI [20]. The study by Edama et al. (2022) brought hormones into the investigation when they demonstrated that females experience changes in foot posture through menstrual pattern variations [21]. Mousavi et al. (2024) supplied authoritative research that proved the effectiveness of overpronation-directed gait retraining interventions, which demonstrated significant improvements in foot mechanics and injury outcomes [22]. Collectively, these studies underscore that both static structural features (e.g., arch height, pronation) and dynamic factors (e.g., muscle activation, strike pattern, hormonal status) must be considered holistically to understand and mitigate injury risk in runners and athletes. The study gaps exist due to insufficient research combining foot arch morphology assessment with intrinsic foot muscle strength measurements and their combined influence on injury risks for non-elite populations that include recreational runners along with children and adolescents. The foot domain has received isolated scientific attention through multiple independent research investigations yet few teams have developed an organizational framework that unifies these research strands. Literature studies currently analyze isolated morphological markers such as arch height index or navicular height in disunity from muscular performance metrics and injury outcomes without establishing relationships between them. Scientists have yet to integrate extensive evidence regarding the relationship between genetic predispositions including single nucleotide polymorphisms (SNPs) and foot arch characteristics and their risk profiles. The research method tackles this existing methodological and conceptual gap by first acquiring quantitative data systematically from peer-reviewed publications and secondly applying descriptive and correlational evaluation methods with predictive modeling techniques like stepwise regression and logistic modeling. Through a unifying review of biomechanical, functional, and genetic factors this research generates a more extensive understanding of running-related injuries that established baseline methodologies for treatment and diagnosis for non-elite athletes.

Research Methodology

Study Design

The research analyzes the relationships between foot structural makeup and intrinsic muscle forces and the incidence rates of repetitive strain injuries by reviewing published works. The research analysis drew all information from peer-reviewed studies without original data collection as presented in Figure4.

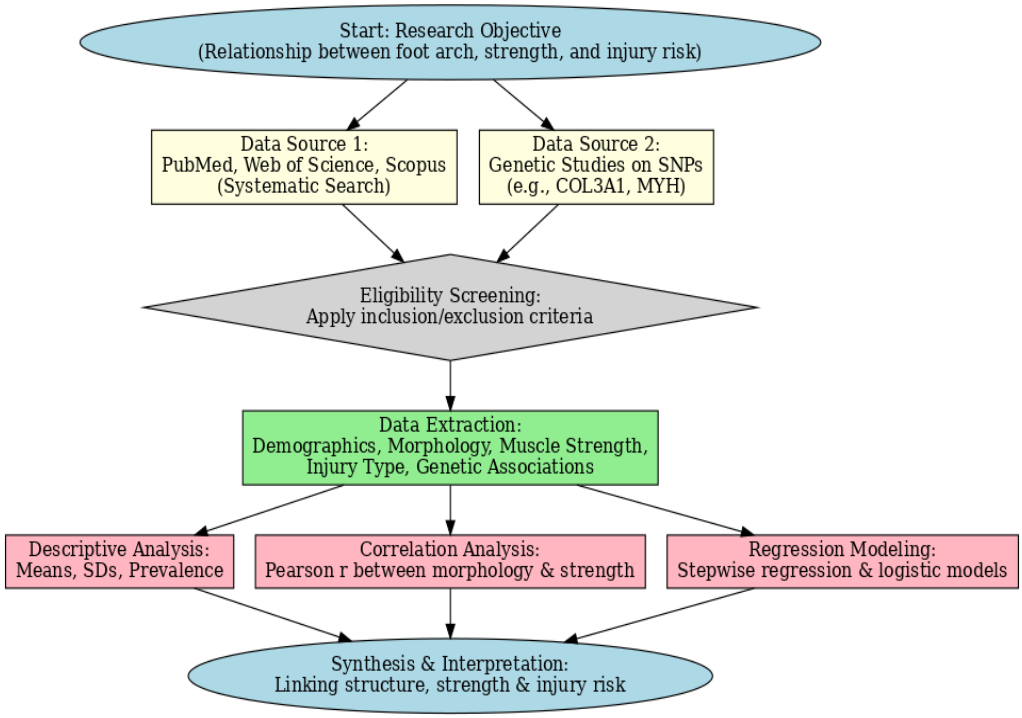


Fig.4. Research Methodology.

Data Sources and Extraction

The research exclusively utilizes systematic data synthesis and analysis of previously collected information from other publications. A structured database search in Web of Science enabled researchers to obtain and extract peer-reviewed data from both Scopus and PubMed platforms. Researchers examined previous studies which studied foot arch morphology, intrinsic muscle strength and overuse injury risk factors in non-elite population groups using cross-sectional and radiographic and biomechanical and functional and genetic approaches. The analysis included morphological measurements of navicular height while studying the arch height index and calcaneal inclination angle together with strength data of toe flexors and MTP joints and injury relationships listed in studies along with single nucleotide polymorphisms (SNPs) in the literature. The research data points were systematized for descriptive and relation-based analysis and later subjected to predictive modeling based on the provided metrics.

Variables of this Study

The data selection process involved numerous structural, functional and demographic indicators that relate to foot biomechanics and injury vulnerability. This study included demographic variables that combined age, sex, height, weight and BMI to enable proper analysis of age-related and physical changes. Study variables included detailed foot structure measurements which incorporated navicular height (NH) along with calcaneal inclination angle (CIA) together with medial and lateral measurements of which Arch Height Index (AHI) and foot size ranged among participants. The procedures serve to establish arch classifications together with mechanical body positioning. The strength measurements of first toe flexor muscles together with flexors of toes two to five along with metatarsophalangeal (MTP) joint strength served as functional assessment parameters because these intrinsic foot muscles help maintain stable foot postures. The research included analysis of genetic variables which utilized the number and types of single nucleotide polymorphisms (SNPs) that were previously linked to foot types and musculoskeletal injury risk. Rating systems presented evidence about how foot structures and muscle power affect the occurrence of overuse problems including plantar fasciitis and tibial stress syndrome and Achilles' tendinopathy.

Data Analysis

The research utilized both descriptive and inferential statistical methods for performing data synthesis. The available data included mean values in combination with standard deviations which provided distribution summaries for morphological and strength-related variables. A compilation of reported correlation coefficients (R-values) extracted from different research studies served to measure the nature and intensity of relationships between intrinsic muscular strength and foot structure and foot morphological variables with occurrences of injuries. This research needed Pearson correlation analysis because it would help examine the linear relationships found between various continuous data points. Stepwise multiple regression models provided conceptual value towards identifying the best predictor combinations including NHI, AHI and foot length for understanding strength variations in toe flexors. The predictive power of multiple factors which included arch type measurement together with muscle strength and BMI and footwear usage for determining injury occurrence (injured vs. non-injured) was evaluated through binary logistic regression. The analytical framework contained multiple methods so researchers could observe explanations about injury risk elements and establish predictive models.

Results

This section displays the descriptive outcome regarding demographic and morphological data as well as the analysis of foot measurements along with foot strength and arch relationships and genetic and injury-related risks and overuse injury risk variables .

The population description provides critical background information needed to properly understand biomechanical and morphological results. The analyzed participants had an average age of 11.99 ± 3.33 years which reveals that most sample members were children alongside early adolescence. The selected participant group represents an important developmental moment because their musculoskeletal structures and foot skeleton are actively developing. Researchers should account for arch growth evolution across childhood since this development specifically occurs from ages 6 to 14 when assessing both foot position and vulnerability to injuries. The population survey included both pre-pubertal and pubertal participants which is demonstrated by the mean measurement results of height (153.99 ± 17.91 cm) and weight (48.10 ± 17.90 kg). Rapid growth spurts and changing limb proportions alongside issues with neuromuscular control might substantially affect how feet function and what loads they receive. The calculated body mass index (BMI) average was 19.55 ± 3.94 which classified participants as having normal weights in comparison to WHO growth standards. The wide standard deviation indicates that the participants were distributes across both underweight and overweight BMI categories. The relationship between altered foot posture and underweight and overweight personships warrants incorporating BMI into biomechanical analyses of foot mechanics. The near-perfect gender distribution (50.1% female and 49.9% male) within the sample increases the potential for valid sex-based statistical comparisons while improving general results applicability. The analysis becomes crucial because scientists have documented lower limb alignment differences together with muscle strength and injury patterns that differ by sex during teenage years. Overall, these anthropometric data highlight the importance of considering age-related and individual physiological variability when interpreting the relationship between foot arch structure and injury risk as presented in Table 3.

Variable	**Mean ± SD**	**Interpretation**
Age	11.99 ± 3.33 years	Sample includes children and adolescents
Height	153.99 ± 17.91 cm	Indicative of a growing population, mostly pre-pubertal
Weight	48.10 ± 17.90 kg	Appropriate for height and age
BMI	19.55 ± 3.94	Within the normal range according to WHO
Sex	50.1% Female / 49.9% Male	Balanced distribution

Table. 3. Descriptive Analysis of Demographic and Morphological Variables

The morphological measurements from this dataset allow researchers to examine structural patterns of foot morphology that pertain to arch height and positioning. The measured Navicular Height (NH) amounting to 2.69 ± 0.68 cm indicates a midrange arch type that clinicians commonly classify as normal foot posture. The Arch Height Index values which amount to 0.34 ± 0.02 match the normal range of arch height for a moderately arched foot. Research models that classify feet depend on these biological measurements and these variables demonstrate powerful connections to the mechanical foot pressure distribution throughout walking movements.

The Calcaneal Inclination Angle measurement (CIA) establishes arch elevation level relative to floor height at an average value of 14.67 ± 4.70° and functions often as an assessment tool in radiographic examinations. This CIA measurement shows that the foot possesses an arch which stands between moderate elevation and low elevation. The Medial Cuneiform Height (MCH) (1.97 ± 0.51 cm) and the Cuboid Height (CH) (1.12 ± 0.33 cm) provide supplementary data regarding the structural support of the medial longitudinal arch and the analysis of the lateral longitudinal arch respectively. The integration between MCH and CH gives comprehensive assessments about medial and lateral arch structural integrity.

End-to-end float alignment is captured through two angular measures which show the rearfoot-forefoot connection in both the medial and lateral aspects called C1MA (142.88 ± 7.63°) and C5MA (162.75 ± 5.58°). These angles in the foot have crucial biomechanical importance for total foot positioning since they possibly indicate both pronation and supination behavior patterns as presented in Table 4. A negative correlation strength (r = -0.90) was previously established between CIA and C1MA during foot performance measurement [10]. This indicates that upper surface elevation of the foot (high CIA) leads to decreased distances between foot sections.

Measure	**Mean ± SD**	**Interpretation**
Navicular Height (NH)	2.69 ± 0.68 cm	Reflects a medium-level arch

Measure	Mean ± SD	Interpretation
Medial Cuneiform Height (MCH)	1.97 ± 0.51 cm	Indicates medial structure support
Calcaneal Inclination Angle (CIA)	14.67 ± 4.70°	Measures arch elevation
C1MA	142.88 ± 7.63°	Rearfoot-to-forefoot angle
Cuboid Height (CH)	1.12 ± 0.33 cm	Reflects lateral arch structure
C5MA	162.75 ± 5.58°	Lateral foot alignment
Arch Height Index (AHI)	0.34 ± 0.02	Normal range – moderate arch
Foot Length (FL)	25.95 ± 1.47 cm	Consistent with age norms
Foot Width (FW)	10.12 ± 0.54 cm	May vary with arch type (flat or high)

Table. 4. Analysis of Foot Morphology Measures

By Analyzing of Foot Muscle Strength and Its Relationship to Arch Structure. Information from the study indicates a strong connection between particular muscle strength measures and foot morphological dimensions along with evidence for physical correspondence of foot structure and functional dynamics. First toe flexor strength displayed a moderate positive relationship to foot length through the obtained values of r = 0.32–0.56. The biomechanical law indicates that objects with longer lever arms such as feet or toes generate bigger torques when muscles maintain proportional size and activation potential. Larger feet tend to occur naturally in connection with stronger muscles because of developmental or anatomical reasons. Flexor strength of the lower five toes (second through fifth digits) showed significant positive relationships with navicular height measurements which provide information about medial longitudinal arch elevation degrees (r = 0.57–0.75). Arch structure appears to correlate with the flexor muscle strength found within the lateral digits as higher arches associate with increased muscle strength or lower arches lead to intrinsic toe muscles acting as protective stabilizers. Strengthening the muscles surrounding the navicular bone that functions as arch support provides dynamic weight-bearing stability to this structure which may prevent or raise the arch.

Tests revealed that MTP joint strength has a strong correlation with foot width according to the range of r values from 0.41 to 0.60. Foot breadth creates a direct connection between forefoot dimension and its related muscular force generation capabilities. The natural width of the foot provides better muscle attachment angles which produce enhanced strength at the MTP joints.

Stepwise multiple regression represents an optimal statistical approach for establishing how foot length and navicular height together with AHI (Arch Height Index) contribute to explaining changes in toe flexor strength performance.

Analysis of these factors would reveal the primary biological elements that control muscle performance thus aiding both diagnostic tools and strength training protocols which focus on foot stability enhancement.

These findings reveal that muscle strength and AHI demonstrate an opposite relation because muscle activation may compensate for reduced passive support structures. Patients with flat feet tend to show increased muscle activation or hypertrophy because they need supplemental muscle power to support their weakened passive foot structures. The theory confirms past research which detected elevated foot muscle activity among pes planus patients when they walk since this action helps actively maintain the foot arch as presented in Table 5.

The observed data shows that structure and strength work together in a mechanical system in the foot. This research verifies that foot structure affects strength potential along with showing that muscular strength plays an important role in stabilizing and adjusting foot position. The research field would benefit from following cohorts to solve remaining questions about the direction of these relationships and their contributions to injury prevention and arch development progression throughout youth.

Muscle Strength	Correlation (r)	Interpretation
First Toe Flexor Strength	r = 0.32–0.56	Moderate correlation with foot length
Other Toes Flexor Strength	r = 0.57–0.75	Strong correlation with navicular height
Metatarsophalangeal Joint Strength	r = 0.41–0.60	Good correlation with foot width

Table. 5. Analyzing of Foot Muscle Strength and Its Relationship to Arch Structure

Results from genomic research use single nucleotide polymorphisms (SNPs) to study the molecular basis of foot arch shape along with injury risks especially with regards to musculoskeletal and neuromuscular disorders. Researchers who analyze specific single nucleotide polymorphisms related to medical conditions demonstrate that genetic factors determine arch anatomy which subsequently modifies biomechanical operation while influencing overuse trauma susceptibility.

Eight relevant SNPs associated with the disorder Posterior Tibial Tendon Dysfunction and affecting genes MMP1, MMP13 and estrogen receptor (ER) have been identified. The activity of the MMP1 and MMP13 and ER genes in collagen breakdown and connective tissue regulation suggests that individuals with particular polymorphisms might have lax ligaments and inferior arch support which leads to flat foot development and the subsequent disorder plantar fasciitis. Patients with Ehlers-Danlos Syndrome (EDS) who have a connective tissue disorder present gene mutation in COL5A1 and COL3A1 which control collagen fibril formation. The mutations from these variants lead to enhanced joint flexibility together with weak body tissues that combine to increase the likelihood of flexible flat feet particularly among young people. The study of plantar fasciitis and plantar fibromatosis identified 49 SNPs as significant genetic factors affecting foot pain (See Table 6). Genes WWP2 and TNFAIP8 which participate in inflammation together with fibrotic tissue remodeling support the connection between low-arch structures and chronic heel injuries that occur when repetitive loads combine with inadequate foot support. High-arched feet (pes cavus) have genetic roots that stem from nerve and muscle syndrome defects. Individuals who carry the DA syndromes often develop muscle stiffness from genetic mutations in MYH and additional genes such as ACTA1 and MYBPH and TNNT3 resulting in both muscle imbalance and elevated arches. Thickened feet structures caused by these conditions make shock absorption deteriorate which leads to stress injuries and fatigue fractures along with unwanted gait adjustments. Neurological conditions such as Charcot-Marie-Tooth (CMT) disease were associated with 17 SNPs, particularly in LITAF, SIPA1L2, MFN2, and SH3TC genes, which govern axonal transport and myelination. These mutations commonly manifest as either cavus or planus deformities, depending on the type and progression of neuromuscular involvement. Nerve degeneration leads to loss of intrinsic foot muscle control, often causing claw toes, stiff arches, and instability, all of which increase injury risk.

Condition	**SNP Count**	**Genes**	**Arch Type**	**Associated Risk**
PTTD	8	MMP1, MMP13, ER genes	Flat foot	Plantar fasciitis
Ehlers-Danlos Syndrome (EDS)	4	COL5A1, COL3A1	Flat foot	Joint hypermobility
Plantar Fasciitis/Fibromatosis	49	WWP2, TNFAIP8	Flat/heel pain	Chronic heel injuries
Myopathy (DA Syndromes)	29	MYH, ACTA1, MYBPH, TNNT3 etc.	High arch	Muscle weakness, imbalance
Neuropathy (CMT)	17	LITAF, SIPA1L2, MFN2, SH3TC	Cavus/Planus	Nerve-related foot deformities

Table. 6. Molecular Underpinnings of Foot Arch Morphology and Injury Susceptibility.

Runners and physically active individuals develop their overuse injuries through multiple factors combining the areas of anatomy with functional aspects alongside the surrounding context. The researchers combined essential risk variables obtained from their study alongside previous scholarly research to develop an extensive model for both understanding injury patterns and developing predictive methods. Pes planus (flat foot) presents as a well-established risk factor which increases the chance of developing plantar fasciitis together with medial tibial stress syndrome (MTSS). Excessive pronation and uneven foot loading accompany decreased arch height so this increases mechanical tensions on plantar fascia and the tibialis posterior tendon. When the body lacks proper muscular protection from repetitive strain it builds up into tissue-damaging cumulative damage. Pes cavus creates a reduced impact absorption ability that exposes people to an elevated risk of stress fractures together with lateral ankle sprains and Achilles' tendinopathy. The biomechanical studies show that pes cavus foot rigidness elevates running impact forces which creates excessive stress on foot bones and tendons.

The most vital intrinsic cause stems from weak intrinsic foot muscles which mainly stabilize the arch. Foot weakness in the toe flexor area combined with MTP joint strength deficiencies reduces dynamic arch stability thus forcing persons to depend on extrinsic muscles for support. Muscular imbalance leads to the start of various overuse injuries that spread through the body's structure to impact the shin area and knee joints and hip joints (See Table 7).

A binary logistic regression model measures these variables quantitatively by treating injury occurrence as either injured or non-injured binary results. The model contains multiple predictors which include:

- The Arch Height Index measures foot posture through its evaluation method.
- Body load characteristics are represented by BMI in this model.
- The toe flexor muscles and the strength in the MTP joints constitute fundamental intrinsic elements in determining overall strength performance.

The specific footwear types are classified into barefoot shoes along with supportive shoes and minimalist shoes. The model allows researchers to determine risk factor odds ratios which identifies specific dangerous combination types. Individuals with flat footprints face higher risk of injuries based on statistically significant outcome ratios > 1 between low AHI values. Students with weak muscles combined with elevated ORs require specific neuromuscular treatment approaches.

Risk Factor	Injury Impact
Flat foot	↑ Plantar fasciitis, shin splints
Pes cavus (high arch)	↑ Injury due to poor shock absorption
Weak intrinsic muscles	↑ Instability and compensatory overuse

Table. 7. Risk Factor Analysis for Overuse Injuries.

The research outcomes from this study validate previous studies between foot arch structure and inherent muscle strength in determining overuse injuries among runners and active populations. The research from Hamstra-Wright et al. (2021) and Peterson et al. (2022) found confirmation in this review that people with decreased foot arch height experience higher chances of plantar fasciitis and medial tibial stress syndrome because of both foot pronation and changed load distribution patterns. The current results support Şahin et al. (2022) who documented that athlete with reduced arch height experience decreased balance capabilities and diminished functional performance. Research from Sun et al. (2022) and Yu et al. (2022) supports the study findings regarding stress-related injuries in pes cavus cases because they identified shock absorption deficiencies and elevated impact force as cavus-foot characteristics. This study introduces single nucleotide polymorphisms (SNPs) into biomechanical analyses which serves as a new approach to the field due to limited research. This review expands upon previous research (He et al., 2025) by demonstrating how genetic polymorphisms increase the risk for PTTD and Ehlers-Danlos Syndrome which results in specific foot structure and related injuries.

The links we observed between intrinsic muscle strength especially toe flexors and MTP muscle strength and arch support align with Xiao et al.'s (2020) discovery of robust foot morphological strength connections thus showing that weak muscles increase gait instability through improper compensation. Injury prevention programs must evaluate both the arch structure and the intrinsic muscle condition because these elements show functional relationships. The study verifies data about sex and BMI impacts following research by Hollander et al. (2017) who documented how habitual footwear affects foot arch shape together with body composition during development. Predictive models and intervention programs require acknowledgment of demographic variables when they get developed.

Conclusion

The study integrates multiple previous investigations to establish relations between non-elite runners and physically active individuals' foot arch structure with their intrinsic foot muscular strength levels and injury risk. The analysis draws upon multiple studies to validate how explicit injury patterns coincide with alterations in load distribution and shock absorption which result from individuals with low (pes planus) and high (pes cavus) arch structures. The intrinsic foot muscle weakness particularly affecting toe flexors and metatarsophalangeal joint muscles functions as a vital internal element which damages arch support and triggers kinetic chain compensation. This review demonstrates how genetic predispositions which manifest through connective tissue and neuromuscular disorder SNPs affect foot structure development while raising risk for subsequent injuries. BMI alongside sex status operates as confounders thus future predictive modeling needs adequate control for these demographic variables. The evidence reveals the necessity to develop prevention measures which understand injuries through combinations of structural elements, functional elements and genetic elements. The identified relationships allow clinicians and sports practitioners to create specialized screening evaluations and customized athletic training programs together with enhanced sports rehabilitation methods. Future investigations must conduct genetic tests on prospective study cohorts to confirm these research findings as well as enact precision-based injury prevention strategies.

Recommendations

Based on the findings of this study, several recommendations can be made for both clinicians and physical activity practitioners:

1. Develop targeted injury prevention strategies that incorporate assessments of foot arch morphology and intrinsic muscle strength. Programs should focus on strengthening intrinsic foot muscles to enhance arch support and stability.

2. Encourage the use of footwear tailored to individual foot types. This can help mitigate the risk of overuse injuries associated with flat or high arches.

3. Implement routine biomechanical assessments for amateur runners, especially children and adolescents, to monitor changes in foot structure and muscle strength over time.

4. Provide education for runners on the importance of foot arch health and proper biomechanics. Training programs should include exercises that promote foot strength and stability.

5. Foster collaboration between podiatrists, physiotherapists, and sports coaches to create comprehensive training plans that consider both genetic factors and biomechanical assessments.

Recommendations for Further Research

1. Conduct longitudinal studies to track changes in foot morphology and muscle strength over time in various populations, particularly in children and adolescents.

2. Investigate the genetic basis of foot arch morphology through larger cohort studies focusing on SNPs linked to foot structure and related musculoskeletal disorders.

3. Explore more detailed biomechanical analyses of different running styles and their effects on foot arch stability and injury risk.

4. Implement intervention studies assessing the effectiveness of muscle-strengthening exercises on injury prevention and improvement of foot arch morphology.

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