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Arch index and running biomechanics in children aged 10–14 years

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ABSTRACT

Background: While altered foot arch characteristics (high or low) are frequently assumed to influence lower limb biomechanics and are suspected to be a contributing factor for injuries, the association between arch characteristics and lower limb running biomechanics in children is unclear.
Research question: Therefore, the aim of this study was to investigate the relationship between a dynamically measured arch index and running biomechanics in healthy children.
Methods: One hundred and one children aged 10–14 years were included in this study and underwent a biomechanical investigation. Plantar distribution (Novel, Emed) was used to determine the dynamic arch index and 3D motion capture (Vicon) to measure running biomechanics. Linear mixed models were established to determine the association between dynamic arch index and foot strike patterns, running kinematics, kinetics and temporal-spatial outcomes.
Results: No association was found between dynamic arch index and rate of rearfoot strikes ($p = 0.072$). Of all secondary outcomes, only the foot progression angle was associated with the dynamic arch index ($p = 0.032$) with greater external rotation in lower arched children.
Significance: Overall, we found only few associations between arch characteristics and running biomechanics in children. However, altered foot arch characteristics are of clinical interest. Future studies should focus on detailed foot biomechanics and include clinically diagnosed high and low arched children.

1. Introduction

Foot arch characteristics have frequently been assumed to influence lower limb walking and running biomechanics and are believed to be a contributing factor for injuries [1,2]. Low foot arches are common in young children while the exact prevalence in older children is a controversial topic [3,4]. Current systematic reviews report a prevalence of around 4–15% of flat feet in school children [3,4].

There have been several studies investigating the relationship between foot arch morphology and lower limb biomechanics in walking [2] with little evidence for altered lower limb motion in participants with flat feet [5]. Only few studies investigated paediatric populations showing longer steps in high-arched children [6] and altered knee and hip kinetics in low-arched children [7]. Other studies involving children found that low-arched participants have reduced hindfoot relative to tibia dorsiflexion and increased forefoot abduction (during stance) [8] or no altered lower limb kinematics [9]. A systematic review by Buldt et al. [2] revealed a high heterogeneity of current research on gait with several different measurements of arch characteristics, such as arch height index [7,10], Chippaux-Smirak Index and Keimig-Index [6], as well as radiographical [11] or clinical diagnoses [5].

In contrast, for running the arch height index was predominantly used to determine high- or low-arched individuals with different cut-off values, such as 0.5 or 1.5 SD [12,13] or quartiles [14]. Studies investigating the effects of foot arch characteristics on running biomechanics report greater peak knee abduction moments and delayed initial medial force peaks for runners with low arches [15]. In contrast, high-arched runners exhibit smaller peak ankle and mid-forefoot eversion [10], higher forefoot abduction [14] and increased vertical loading rates [16]. Furthermore, an interaction of footwear and arch characteristics was observed for initial loading rates [12] and different injury patterns were reported for high-arched and low-arched runners [1].

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Even though the foot arch is a dynamic structure [17] most of the studies used a static evaluation of the foot arch. Results from studies considering dynamic foot arch evaluations are currently missing [2]. Furthermore, to the best of the author's knowledge, all research reporting on the relationship between arch characteristics and running biomechanics investigated adult populations. For paediatric populations the effects of arch characteristics on running biomechanics has not yet been investigated.

Therefore, the aim of this study was to evaluate the association of a dynamically measured foot arch and lower limb biomechanics in children. Since this is the first study to evaluate this relationship, findings from adult populations were used to select relevant kinematic, kinetic or temporal-spatial outcome variables that might be influenced by arch characteristics.

2. Methods

2.1. Study design and participants

For this cross-sectional study, healthy children aged 10–14 years were recruited from local schools and sport clubs. Inclusion was not restricted to a certain foot type in order to represent a broad range of foot arch indices. Any musculoskeletal injury that occurred in the six months prior to the investigation as well as orthopaedic, neurological or neuromuscular abnormalities likely to affect gait led to exclusion from the study. Prior to the investigation, children's assent and written parental (or legal guardian's) consent was obtained. Ethical approval was obtained from the local ethics committee (protocol number PV4971). Reporting of this study adhered to the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) statement for reporting observational studies [18].

2.2. Setting

The study took place in the gait laboratory of a children's hospital that was instrumented with an eight camera infrared motion capturing system (200 Hz, VICON, Vicon Motion Systems Ltd., Oxford, UK) and two force platforms (1000 Hz, OR-6-7-2000; AMTI, Watertown, MA, USA). Two high-speed cameras (50 Hz, Basler AG, Ahrensburg, Germany) positioned in parallel and orthogonally to the walkway were synchronised to the motion capturing system. Furthermore, a pedobarographic capacitance-based pressure platform (50 Hz, Emed n50, Novel GmbH, Munich, Germany) embedded in a 7-m walkway was used.

2.3. Data measurement and variables

2.3.1. Dynamic arch index measurement

To determine the independent variable "dynamic arch index", children walked at a self-selected speed over the pedobarographic platform (Emed n50, Novel GmbH, Munich, Germany). Children were instructed to walk over the walkway as normal as possible and not to target for the platform. A two-step approach was used since it has been shown to be reliable in children [19]. After several familiarisation trials, participants walked over the platform in a bidirectional manner until five left and five right foot trials were measured. The five pedobarographically acquired footprints per side were then, respectively, used to calculate the dynamic arch index by dividing the foot into longitudinal thirds. The middle third of the foot area was then divided by the whole foot area (excluding the areas of the toes) [20]. Thus, the dynamic arch index is a ratio of contact areas and is reported in percent. High dynamic arch index values represent a flat foot arch and vice versa.

2.3.2. 3D running biomechanics

Each child underwent a three-dimensional running gait analysis (VICON, Vicon Motion Systems Ltd., Oxford, UK) using the plug-in gait lower body marker set (15 markers, 14 mm diameter). After a static calibration trial and habituation trials, children ran barefoot at a self-selected comfortable speed over a 10-m walkway. Kinetic data was obtained by two level force plates (AMTI, Watertown, MA, USA). A minimum of 10 trials striking the force plates per side were captured. To determine the primary outcome, two independent investigators rated the footstrike pattern using the video data of the two high-speed cameras (Basler AG, Ahrensburg, Germany). This video-based method for footstrike pattern detection was already used successfully in other studies and has a good reliability and validity [21].

2.4. Data processing

Data acquisition and processing were carried out using the Vicon software (Nexus 1.8.2 and Polygon 4.1; Vicon Motion Systems Ltd.) and Python (2.7.10; Python Software Foundation). Kinematic data were filtered (Woltring filter, predicted MSE value: 10). Force plates were zeroed prior to data capture and kinetic data filtered using moving average (10 ms). Effects of foot arch characteristics were expected during non-rearfoot barefoot running. Therefore, for secondary outcomes, processed biomechanical data of non-rearfoot strikes were used to calculate all dependent variables. Rearfoot strikes were excluded for secondary outcomes due to biomechanical differences between foot strike patterns especially when running [22]. A child was included in the analysis of secondary outcomes if at least three non-rearfoot striking trials were captured. Relevant regions of interest were selected to be comparable to previously published studies on the effect of or relation between foot arch characteristics on/and running biomechanics in adults [10,12–16]. Accordingly, the sagittal plane kinematics (ankle, knee and hip), as well as foot progression angles were calculated at ground contact. For kinetics, the maximum of the ground reaction force (GRF) curve was determined and the loading rate calculated as the slope of the GRF curve for the first 10% of stance phase. The maxima of joint moment curves were used to determine knee peak abduction, knee peak extension, hip peak extension and ankle peak plantar flexion moments. For temporal-spatial outcomes step length & time, stride length & time and cadence were exported.

2.5. Statistical methods and study size

For descriptive purposes, all outcome measures are presented with means ± standard deviations (SD), or 95% confidence intervals (95%CI). Variables were compared according to their statistical distribution. A generalized linear mixed model for a negative binomial distribution was applied to estimate the effect of dynamic arch index (fixed effect) on foot strike pattern. Children were included as a random intercept and two different models were calculated. While one model (model 1) was unadjusted, the second model (model 2) was adjusted for height, BMI and velocity. Subsequently, linear mixed models were calculated to assess the effect on the dependent variables of running kinematics (ankle plantarflexion, knee flexion, hip flexion and foot progression angle at ground contact), kinetics (maximum GRF, impact loading, as well as knee peak abduction, knee peak extension, hip peak extension and ankle peak plantar flexion moments) and temporal-spatial outcomes (cadence, step length, step time, stride length and stride time). A p-value < 0.05 was considered to indicate statistical significance. All statistical analyses were performed with IBM SPSS Statistics 23.0 (SPSS, Chicago, IL).

3. Results

3.1. Participants

We included 101 children for final data analysis (45.5% females, mean ± SD age 12 ± 1.3 years, height 156.9 ± 10.4 cm, weight 45.7 ± 9.6 kg, BMI 18.4 ± 2.2). Of all potential participants