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Review

Flatfeet: Biomechanical implications, assessment and management

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ABSTRACT

Several complications due to flatfeet have been reported in previous literature such as poor postural stability, injuries, pathologies, and discomfort. Early detection and appropriate management are mandatory to minimize these effects. There are different feet assessments established in the field with distinct advantages and disadvantages. Additionally, selection of management methods from various options should be done vigilantly as the application differs according to the individual. Therefore, the objective of this article is to review previous literature on structural anatomy, pathomechanics, assessment, and proper management of flatfeet to provide a condensed summary for healthcare professionals, occupational therapists, kinesiologists, biomechanists, coaches, and ergonomists.

1. Introduction

Flatfeet (pes planus) is well-known to have an association with a higher incidence of lower extremity injuries in the population [1–3]. The reason for this could be altered foot kinetics [2,3] or poor postural stability due to abnormal foot structure [4]. According to previous studies, prevalence of flatfeet is reported to be around 25% in the general population (26.62% [5], 25.3% [6]). This prevalence appears to be higher in females [5,6], individuals with a higher body mass index (BMI) [7], and in individuals with larger feet [5]. The incidence of flatfeet significantly decreases with increasing age; it is 54% at the age of 3 years, 24% at 6 years [7], and 11.25% at 18-25 years [8]. Human foot can be categorized into three categories according to the medial longitudinal arch (MLA) height as normal arched (pes rectus; MLA height 2.57 ± 0.14 cm), low arched (pes planus; MLA height 1.86 ± 0.23 cm) and high arched (pes cavus; MLA height 3.26 ± 0.16 cm) [9]. A separate classification exists to classify the foot as normal, pronated and supinated which frequently uses foot posture index as the classification method [1]. Although this classification reflects a more functional aspect, pronated foot and supinated foot are usually associated with flatfeet and high arched feet respectively [10].

The occurrence of flatfeet can be multifactorial. It could be present since birth (congenital pes planus) or develop later in life (acquired pes planus). African-American ethnicity [11] and female gender [5,6] are associated with congenital flatfeet and the incidence was found to be highest in African-American women [12]. Causative factors suggested for acquired flatfeet include age [5], obesity [7], and not wearing footwear in early childhood [13]. Additionally, improper function of extrinsic and intrinsic foot muscles at birth or later in life has been reported to be a causative factor [14]. Considering the occurrence and abundance of flatfeet among population, it is apparent that flatfeet are an influential factor for quality of life in various categories of the society. These effects can alter activities of daily living, efficiency and injuries in occupational settings as well as injury risk and performance in sports. Therefore, early detection, implementation, and proper management of flatfeet are essential. Thus, the aim of this article is to provide a condensed summary of the structural anatomy, pathomechanics, assessment, and management of flatfeet.

2. Structural anatomy of flatfeet

Flatfeet are an anatomical alteration which can occur in one foot (unilateral pes planus) or in both feet (bilateral pes planus) [15]. The most common structural difference in flatfeet is found to be rear-foot varus which in turn causes excessive pronation of the foot [16]. In addition, deepened navicular cup, widened talus articular surface, proximally faced talus, and higher positioned navicular articular surface can be seen [17]. These alterations cause the MLA to collapse resulting in a loss of arch height. When this loss of arch height is observable in both non-weight bearing and weight bearing positions, it is termed as rigid flatfeet. Contrarily, when a normal MLA height is present in non-weight bearing condition and collapses with weight bearing is identified as flexible flatfeet [18].

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3. Pathomechanics of flatfeet

According to previous literature, there are various kinetic and kinematic alterations in flatfeet compared to normal feet. Among these pathomechanic alterations, greater hindfoot eversion [2,19], greater peak forefoot plantarflexion, greater forefoot abduction, lesser peak forefoot adduction, greater tibial internal rotation [2], greater rearfoot eversion excursion, greater rearfoot eversion velocity [3], sub-talar joint eversion [19] and less abduction of the forefoot during toe-off phase are prominent. These altered movement patterns affect normal gait and balance while increasing injury risk. Additionally, during single leg standing, decreased muscle activity in abductor hallucis, medial gastrocnemius, anterior tibialis, and vastus medialis have been reported in flatfeet [20]. As the abductor hallucis muscle acts as a dynamic stabilizer of the MLA, lower activity in this muscle can lead to lower biomechanical capability, poor absorption of external forces and postural instability causing injuries [20]. Additionally, abnormal alignment of the foot can cause weakening of foot intrinsic muscles (abductor hallucis, flexor hallucis brevis, flexor digitorum brevis, and interosseous muscles) leading to musculoskeletal dysfunction and overuse injuries [21]. Furthermore, second and third metatarsal areas are reported to have concentrated foot pressures in flatfeet compared to the normal arch group during dynamic activities such as walking [19]. Additionally, altered plantar pressure distribution was seen during quiet standing [22] causing poor postural stability and subsequently leading to a higher incidence of lower extremity injuries.

Apart from the mechanical issues, limited literature is available regarding pes planus as a causative factor or an associated factor in certain disease conditions. Osteoarthritis of the foot [23] and recurrent knee pain possibly due to abnormal cartilage damage [23] are associated with flatfeet in elderly individuals. Moreover, co-existence of rheumatoid arthritis of the foot and flatfeet were reported in a group comprised of young adults, middle-aged adults and older adults [24]. Furthermore, subtalar joint eversion in flatfeet can possibly cause weak MLA [19] resulting in a higher contact area than normal foot. Even though this increase in contact surface area can be considered as a larger base of support for postural stability, it has been reported that individuals with flatfeet demonstrate poor static and dynamic balance compared to individuals with normal feet [4]. Although the definite reason for this is not precise, previous researchers have suggested that it could be due to structural and functional alterations of the foot and the inability to absorb external forces [25]. It is also believed that improper foot alignment causing additional stress applied on muscle spindles and tendons of talocalcaneal joint leads to impaired proprioceptive feedback from the foot [4] causing poor balance. Additionally, altered center of pressure (COP) because of abnormal lumbar curvature due to low MLA carries the possibility of poor balance [26]. Moreover, flatfeet cause leg and foot muscles to be more fatigable and can cause cramps and pain due to overuse [27]. This pain varies with each individual where some individuals develop pain with mild exertion and some individuals do not have pain or any other symptoms [28].

4. Assessment methods of foot types

Assessment of foot type has been done in several ways in previous literature. These methods are diversified from a simple visual inspection of the foot to complex methods using high technology instruments. The reference values for classification vary with the type of assessment used. This section and following table deliver a brief summary of such methods (Table 1).

4.1. Visual inspection

4.1.1. Direct visual inspection

By observing the foot from the front, back, and sides in non-weight bearing and weight bearing conditions during quiet standing and motion, foot morphology and magnitude of MLA height will be noted [1]. However, the reliability and validity of this method are controversial [1]. Despite its convenience, this is a subjective and non-quantifying method, therefore can be used only for gross classification of the foot.

4.1.2. Visual inspection of foot photographs

To perform a visual inspection of foot, a photograph is taken in weight-bearing condition and observed by the investigator. The foot is usually placed on an acrylic plate allowing an optimal view of the plantar surface. The use of perpendicular mirrors to get anterior, posterior, medial, and plantar views in one photograph [29] as well as using a mirrored foot photo box [30] have been reported. This method is considered to possess higher reliability and validity similar to the radiologic measurements [30].

4.1.3. Visual assessment of footprints

Visual footprint assessment is done by analyzing a simple ink print of foot taken on to a paper. The imprint caused by the plantar surface of the foot is considered to reflect the magnitude of MLA [31]. However, there have been a significant amount of differences and misclassifications with this method compared to the caliper measurements [32].

4.2. Anthropological measurements of the foot

This is performed using a measuring tape, a ruler [33], or a device specifically designed for this purpose such as arch height index measurement system (AHIMS) to obtain a vertical measurement at the highest point of MLA in sagittal plane. This could be done in both non-weight bearing condition or in weight-bearing condition [34].

4.3. Calculation of arch height index (AHI) as a predictor of the arch height

This is performed using calipers [35], AHIMS [34,36], footprints [31], force plate [37], digital plantar foot photographs [38], or plain X rays [33] in non-weight bearing condition or in weight-bearing condition. Among these, higher reliability and the inter-rater reliability was reported in AHIMS [36].

Above methods are considered as the traditional methods of foot classification. Those are convenient, cost-effective, feasible, readily available, and non-invasive with no requirement of specific devices or high technology.

4.4. Plain radiography

Observation and/or quantitative analysis of an X-ray view of foot is used for categorization [33]. This is considered as a high [39] or moderate to excellent [33] reliable method. However, two-dimensional (2D) view of X-rays seems to be a limitation. Some researchers have suggested that foot arch height could be altered with the axial rotation of tibia [40]. This argument was denied explaining that each individual has a habitual way of keeping their feet while standing, therefore, axial rotation will not affect the foot arch measurement of the same subject during different occasions [31]. The findings from X-ray assessments are frequently used to validate the measurements gathered from other methods such as visual inspection and tape measurements [35]. However, radiation exposure, accessibility, and high cost are some limitations associated.

4.5. Footprints analysis

Analysis of ground contact area of the foot is done with simple ink print on paper [31,41], plantar pressure analyzing plates [42], or with a pressure analysis system such as, Tekscan pressure sensor system [43]. The reliability of footprint analysis is debatable, it carries evidence for both being reliable [43], and unreliable [40]. The Tekscan pressure

Table 1
Summary of previous studies on foot type assessment.

	Assessment method	Methodology	Findings & conclusions
Dahle et al. [1]	Direct visual inspection	59 football players and 18 cross country runners' feet were separately assessed by three trained physical therapists Degree of calcaneal eversion, forefoot abduction, medial bulge of talo-navicular joint, MLA height, and degree of lower extremity internal rotation was observed for classification	Appropriate consistency of the assessment of gross foot type among observers and adequate inter-rater reliability had been identified Conclusion: sufficient training prior to the test is fundamental for a better assessment Note: pronation and supination categorization was done here
Swedler et al. [32]	Visual analysis of footprints Caliper measurements of MLA	3968 army recruits' footprints were assessed by two observers. Caliper measurement of the arch height was taken and compared with visually analyzed results	Significant overlap between foot types and misclassifications were found. Discrepancies were greater with the individuals with higher BMI
Cowan et al. [29]	Visual assessment of the foot photographs	Four-plane photographs of 246 army trainees were independently analyzed by four orthopedic surgeons and two podiatrists Observers were formerly trained in a review and discussion of 40-foot photographs obtained from individuals who did not participate in the actual study	There has been a considerable amount of inter-observer variability, even with the extreme foot types
Weimar and Shroyer [34]	AHIMS	79 female participants' foot arch height and arch height index were measured in sitting and standing position	Significant difference in arch height and arch height index in sitting and standing positions, as well in right and left legs were found Conclusion: both feet should be measured when AHIMS is used for foot classification
Butler et al. [36]	AHIMS	11 subjects were recruited to assess the intra and inter-rater reliability of foot classification using AHIMS. Foot arch height measurement and AHI calculation were done	AHIMS found to have a higher inter-rater reliability
Murley et al. [33]	Navicular height Foot arch index X-ray measurements	Navicular height (distance from the standing surface to navicular tuberosity) and foot arch index of 91 participants were compared with anteroposterior and lateral X-ray measurements (calcaneal-first metatarsal angle, talus-second metatarsal angle, calcaneal inclination angle and talo-navicular coverage angle)	Both navicular height and foot arch index was found to have a significant relationship with X-ray measurements Navicular height demonstrated the strongest relationship with Xray measurements, especially in the lateral views
Cavanagh et al. [39]	X-ray measurements	Quantitative analysis of the navicular height using lateral and dorsi-plantar views of plain radiographs in weight bearing stage in 50 participants was done	Generally high reliability of the radiographic measurements was revealed Conclusion: with the consistency of the observer and use of more than one radiograph, the accuracy and reliability will be higher
Urry and Wearing [41]	Footprint analysis	Footprints of 16 participants were analyzed using a mock pressure platform and an ink print of the foot onto a paper with a grid pattern	Acceptable accuracy was determined Conclusion: lesser toes contact area may have estimated unfairly. This could be improved with the use of smaller sensors

sensor system detects plantar pressures and forces developed by two contacting surfaces [44]. It is increasingly becoming popular since considerable convenience and moderate to good reliability [44]. Additionally, optical pedobarograph is used to analyze plantar pressure distribution [39] which has been rarely used.

4.6. Three-dimensional (3D) motion capture system-Oxford foot model

Cameras synchronized with 3D motion capture analysis system detect trajectories of foot segments through reflective markers attached to the dorsum of the foot [2]. This can be used to assess both foot type and foot dynamics [45]. 3D motion capture system is becoming highly popular in the realm of biomechanics due to high reliability [45].

4.7. Other methods of foot type evaluation

There are many other ways of foot classification which were used by a limited number of scientists such as assessing foot models [46], 3D scanning of the foot [47], fluoroscopy studies [48] and 3D kinematic coupling behavior analysis [49]. Although these methods have higher accuracy and precision, affordability and accessibility are possible practical difficulties.

5. Management of the flatfeet

It is known that flatfeet can affect balance [4], make leg and foot muscles more fatigable [27], cause foot and leg pain [50], increase susceptibility to injuries [1], and have an association with certain diseases [24]. Therefore, it should be properly managed to improve the quality of life. Although each individual may not require an intervention [7] it should be vigilantly addressed when it is associated with pain and functional problems. There are few established methods of flatfeet management which carry their own advantages and disadvantages. Some of these methods could be done in the field while some of those require extensive measurements/technology. The choice of management depends on the individual, severity, situation, requirement, and accessibility to technology and facilities.

5.1. Arch taping and ankle bracing

These are temporary methods which are usually combined with pain-relieving medications in acute settings. Different types of tapes such as elastic, non-elastic (low dye tape/rigid tape) tapes and kinesiotapes are available. Support, pain relief, foot muscle activation, and alteration of plantar pressure distribution vary with type of tapes [51]. It is reported that the non-elastic tape is more effective than elastic tape in flatfeet management [51]. However, application of non-elastic tapes reduces pain but does not change the amount of rearfoot pronation [52]. Kinesiotape is considered closer to human skin and believed to correct flatfeet deformity via increasing proprioceptive feedback from feet, and hence considered superior to traditional taping [53]. While tapes usually adhere to skin and are not reusable, braces are secured using lace or straps and they are reusable. Ankle braces are frequently used with acquired flatfeet than with congenital flatfeet. Nonetheless, braces are found to be successful for a limited time period [54]. Providing support and relieving pain are the predominant uses of ankle braces [54].

5.2. Foot exercise and plantar intrinsic muscle training

MLA is supported actively and passively by surrounding structures. It is actively supported by anterior tibialis muscle, posterior tibialis muscle, peroneus longus muscle, posterior tibial tendon [50], and intrinsic foot muscles (abductor hallucis, flexor hallucis brevis, flexor digitorum brevis, and interosseous muscles) [27]. It is passively supported by the plantar fascia, plantar ligaments, and tarsal and metatarsal bones [55,56]. Foot exercises to strengthen intrinsic foot muscles have been suggested to be helpful in the management of pes planus. It has been reported that these exercises can change plantar pressure distribution and thereby relieve the pain. Moreover, there is evidence of plantar intrinsic muscle training for four weeks can significantly increase balance, decrease navicular drop and increase AHI [14].

5.3. Insoles

Insoles act as a temporary relief for individuals with flatfeet. Insoles improve balance in individuals with a flat arch as well as with a normal arch [57]. Contoured insoles might have better effects than flat insoles as the latter carries the possibility of decreasing local peak pressures of flatfeet [58]. Moreover, therapeutic insoles are considered more valuable since those are shown to reduce talocalcaneal joint eversion in 3D CT models [59]. However, over the counter insoles are not beneficial with flexible flatfeet [60].

5.4. Foot orthotics

A foot orthotic is a support that helps for proper foot alignment and function. It is being widely used as an easy and temporary solution for flatfeet [55]. These are usually prescribed for individuals with flexible flatfeet in less severe stages [61]. Specifically, foot orthotics are used to correct calcaneal eversion, rebuild normal length of abductor hallucis muscle and thereby restore normal foot alignment and function [21]. Additionally, these orthotics are known to escalate the sensory feedback from the medial aspect of the foot [62] helping to maintain postural stability.

Foot orthotics carry the possibility of correcting pes planus deformity [37] and wearing foot orthotics for two months is found to improve the strength of abductor hallucis muscle [21]. In addition, orthotics cause considerable reduction in maximum calcaneal eversion preventing the foot from overpronating [63]. There are radiological evidence of significant improvement in foot structure before and after wearing flexible orthotics [64]. In contrast, the effect on function, rear foot kinematics, and kinetics are unclear [65] and a minimal effect on muscle activity was reported [66]. Therefore, the mechanism of action of orthotics is yet debatable. Similarly, the amount of pain relief with orthotic use is controversial. There is evidence for situations where the pain is relieved and not relieved [67]. Therefore, orthotics might be beneficial, yet the long-term effects are unclear [21]. However, combination of foot exercises and orthotics elicit a better outcome than a single intervention [21].

5.5. Footwear

The role of footwear in the management of flatfeet is unclear [65]. However, there are anthropological and radiological evidence of increasing MLA height following continuous wearing of contoured sandals [68]. In addition, there are numerous studies available regarding footwear effects on foot muscle activity [69] and variations of muscle activity with the footwear type and hardness of the sole [70]. Therefore, it can be concluded that proper footwear can aid in the management of flatfeet. Individuals can use footwear specifically designed for flatfeet or can use insoles or foot orthotics with desired footwear.

5.6. Surgical correction and rehabilitation

Surgical interventions are applied for individuals with a severe degree of flatfeet, with progressive symptoms or complications [56,71] and has been reported to significantly improve the structure and function of the foot [71] and prevent the progression of the deformity [72]. Specifically, surgical release of plantar fascia stiffness found to reduce stress on foot ligaments and bones [56] and calcaneal osteotomy found to improve the function of foot significantly [73]. Rehabilitation following surgery is mandatory for a better outcome.

6. Conclusion

The aim of this article was to provide a condensed summary of the structural anatomy, pathomechanics, assessment, and proper management of flatfeet. It is apparent that pes planus is a prevalent concern which affects discrete groups of the society in various settings. Therefore, knowledge of assessment methods and interpretation of results are essential for the clinicians, coaches and employers for early detection. Early detection is mandatory for proper management, screening for prediction and prevention of injuries. As management of flatfeet differs with severity, situation, requirement, and accessibility to technology and facilities, it should be sensibly distinguished based on the individual.

Conflict of interest

The authors declare no conflict of interest.

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