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Flatfoot in children: anatomy of decision making

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Summary

Concern about a child's foot posture is a common reason for frequent consultations for an array of health care professionals; sports medicine specialists are often the first to recognize and advise on foot pathology. In the decision making process, it is essential to distinguish between the different types of flatfoot deformity: paediatric or adult, congenital or acquired, flexible or rigid. Although flatfoot in children is a common finding, evidence for the techniques of the reliable and reproducible assessment of the foot posture is scant. This general review presents the factors involved in the forming and supporting of the foot arches, discusses the protocols useful in the evaluation of the foot posture, and indicates how to differentiate between flatfoot cases needing treatment and cases that need only reassurance.

Key words

Foot posture; flatfoot; paediatric flatfoot; functional anatomy.

Introduction

The arches of the foot are formed by the tarsal and metatarsal bones, which, passively supported and actively restrained by ligaments and tendons, allow the foot to support the weight of the body in standing position and to distribute adequately the forces generated on contact with the ground during walking. All children are born with flat feet and the normal arches may not develop until they reach the age of 7-10 years (Pfeiffer *et al.*, 2006). The arches develop in early childhood as part of normal bone, ligament, muscle, and tendon growth and strengthening. When misalignment, bones misshape, or weakening of the tendon or ligament occurs, a deformity of feet can develop.

Flatfoot (*pes planus*) is a medical condition in which the entire sole of the foot comes into complete or near complete contact with the ground. Although the most common form is the physiological flatfoot, the progression to a more severe grade of deformity can lead to the development of symptomatic flatfoot, which produces subjective complaints and has an effect on function (Haendlmayer and Harris, 2009). However, the real significance of the clinical findings is frequently misjudged. In a decision making process, it is essential to distinguish between the different types of

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flatfoot deformity: paediatric or adult, congenital or acquired, flexible or rigid. It is also important to recognize factors involved in forming and maintaining the arches of the foot, and to evaluate correctly the foot posture in order to identify flatfoot deformity and differentiate between cases needing treatment and cases that need only reassurance.

Functional anatomy of the foot

The skeletal framework of each foot is formed by 28 bones: 7 tarsals, 5 metatarsals, 14 phalanges and 2 sesamoid bones. From the functional point of view, the feet can be divided in three parts: the hindfoot, formed by talus and calcaneus, the midfoot, consisting of navicular, cuboid and three cuneiform bones, and the forefoot, formed by metatarsals and phalanges (Moore *et al.*, 2010). The talus, calcaneus, cuboid, navicular and three cuneiform bones form the tarsus, comprising the hindfoot and midfoot.

The hindfoot extends from the calcaneal tuberosity to the transverse tarsal joint (Chopart's joint); the latter consists of the talonavicular part of talocalcaneonavicular joint and the calcaneocuboid joint. The anterior limit can be traced on the surface along the S-shaped line (medially convex and laterally concave) connecting the tuberosity of the navicular bone (palpable inferoanteriorly to the tip of the medial malleolus) with the point located half-way between the lateral malleolus and the tuberosity at the basis of the 5th metatarsal. The movements of the midfoot on the hindfoot at the transverse tarsal joint augment the inversion (turning the sole towards the median plane) and eversion (turning the sole laterally), occurring mostly at the subtalar joint. The anterior limit of the midfoot follows the tarsometatarsal joints (Lisfranc's joint), traced on the surface by the slightly convex line between the tuberosity of the 1st and the prominent tuberosity of the 5th metatarsal bone. These joints allow only slight movement of sliding (Riola and Palma, 2001).

The shape of the tarsal and metatarsal bones accounts for the presence of longitudinal and transverse arches of the foot. The medial longitudinal arch extends between the calcaneus and talus (posterior pillar), and first three metatarsal and three cuneiform bones (anterior pillar). The keystone, corresponding to the talar head, is 15-18 mm above the ground. The lateral longitudinal arch is much flatter and rests on the ground in the weightbearing feet. It is composed of the calcaneus (posterior pillar), the lateral two metatarsals (anterior pillar) and the cuboid bone (keystone), which may be 3-5 mm from the ground in the non-weightbearing feet. The transverse arch runs from side to side at the tarsometatarsal joint level. Its medial pillar is represented by the medial cuneiform and the basis of the 1st metatarsal bone, the lateral pillar is formed by the lateral cuneiform, cuboid and the bases of the 3rd-5th metatarsals; the keystone corresponds to the intermediate cuneiform, which can be 18-20 mm above the ground (Moore *et al.*, 2010).

The arches are passively maintained by plantar aponeurosis and ligaments (long and short plantar ligament, plantar calcaneonavicular ligament) and dynamically supported by tendons of extrinsic muscles (tibialis anterior, flexor hallucis longus and brevis, flexor digitorum longus and brevis for the longitudinal arch; peroneus longus, tibialis posterior for the transverse arch) and by intrinsic muscles that run between the pillars of the arches. These structures act together as a unit to support and distribute appropriately the body weight during walking.

Evaluation of the foot posture

Although flatfoot in children is a common finding, evidence on the techniques of the reliable and reproducible assessment of this condition seems scant. A wide array of methods is used, from visual observation of foot and footprint to clinical and radiographic measurements. Importantly, only few of the protocols have been normalized and are characterized by reliability and reproducibility to such a degree to make them useful in the evaluation of flatfoot natural history, essential for the diagnosis of paediatric flatfoot.

Visual observations

Six visual observations have been combined by Redmond *et al.* (2006) into the Foot Posture Index (FPI-6), a validated diagnostic tool aimed at quantifying the degree to which a static, weightbearing foot can be considered to be in a pronated, supinated or neutral position (of note, pronation involves eversion and abduction, while supination consists of inversion and adduction). Every component is graded 0 for neutral, -1 or -2 for signs of supination, and +1 or +2 for signs of pronation (Table 1). The final score is a number between -12 and +12 (Redmond *et al.*, 2008). A slightly pronated foot posture is the normal position at rest, with the mean FPI score +6 in the minors (3-17 years), +4 in the adult population (18-59 years), and +5 in the elders (60+ years). While age influences foot posture, no relationship was found between body mass index (BMI) or sex and FPI.

Clinical measurements

Arch index

The footprint is taken using carbon paper and the length of the foot (excluding toes) is divided into equal thirds. The arch index (AI) is calculated as the ratio of the area of the middle third of the footprint to the entire footprint area (Fig. 1). Normal foot is characterized by the AI ranging from 0.20 to 0.28, while the ratio higher then 0.32 indicates a flat-arched foot (Murley *et al.*, 2009).

Although it is comprehensible that the AI may be confounded by variations in soft tissue composition, ultrasound tests revealed that there was no significant difference in the thickness of the midfoot plantar fat between overweight/obese pre-school children and their non-overweight counterparts (Mickle *et al.*, 2009). Hence, the finding of higher AI in the overweight/obese children indicates the actual lowering of the medial longitudinal arch.

Normalised navicular height

Normalised navicular height (truncated, NNHt) is the ratio of navicular height (measured as the distance from the most medial prominence of the navicular tuberosity to the supporting surface) related to the truncated length of the foot (from the

Table 1. Evaluation of foot posture based on visual observation. Adapted from Redmond (2005).

Score	-2 (supinated)	-1	0 (neutral)	+1	+2 (pronated)
Hindfoot					
Talar head palpation (talo-navicular congruence)	Palpable on lateral, but not on medial side	Palpable on lateral and only slightly on medial sight	Equally palpable on both sides	Palpable on medial, but only slightly on lateral side	Palpable on medial, but not on lateral side
Curves above and below the malleolus	Infra-malleolar curve straight or convex	Infra-malleolar curve concave but flatter then supra-malleolar curve	Infra- and supra-malleolar curves equal	Infra-malleolar curve more concave then supra-malleolar curve	Infra-malleolar curve markedly more concave then supra-malleolar curve
Calcaneal inversion/ eversion (relaxed calcaneal stance position, RCSP)	more then 5º inverted (varus)	between vertical and 5º inverted	vertical	between vertical and 5º everted	more then 5º everted (valgus)[1], Achilles tendon may bow laterally (Helbing's sign)
Midfoot					
Talo-navicular congruence	markedly concave	slightly concave	area of talo-navicular joint flat	bulging slightly	bulging markedly (convex)
Medial arch height	arch high and posterior pilar acutely angled	arch moderately high and slightly acute posteriorly	arch height normal and concentrically curved	arch lowered and slightly flattened in the central portion	arch making ground contact
Forefoot					
Forefoot abduction/ adduction (too many toes sign)	no lateral toes visible, medial toes clearly visible	medial toes clearly more visible then lateral	medial and lateral toes equally visible	lateral toes clearly more visible then medial	no medial toes visible, lateral toes clearly visible

1 In the flexible flat foot, the everted heel changes to a varus position when a patients is advised to rise to toes.

1st metatarsophalangeal joint to the most posterior aspect of the heel, Fig. 1). Values lower then 0.21 indicate flat-arched foot (Murley *et al.*, 2009).

In young adults, NNHt provided the strongest correlation with the radiographic measurements. Both clinical measurements (AI and NNHt) can be successfully used in screening for flat foot posture, avoiding unnecessary referral for radiographic

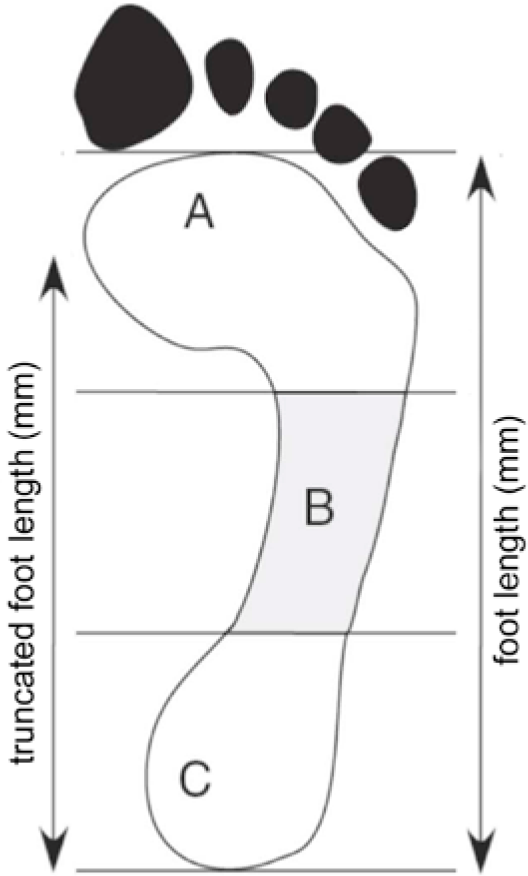

Figure 1 – Clinical measurement of arch index (AI=B/A+B+C). Modified from Murley *et al.* (2009).

assessment, and they are recommended for the recruitment of participants into foot posture studies (Murley *et al.*, 2009).

Radiographic measurements

Radiographic examination of foot deformities is useful for diagnostic evaluation and documentation of the degree of deformity; it becomes essential for pre-operative planning and assessment of therapeutic results. In flatfoot, it focuses on the relationship of the talus and calcaneus, which can be assessed in the sagittal plane on the lateral view and in the transverse plane on the anterior-posterior (A-P) view radiographs obtained with the subject weight-bearing in a relaxed bipedal stance position (Murley *et al.*, 2009).

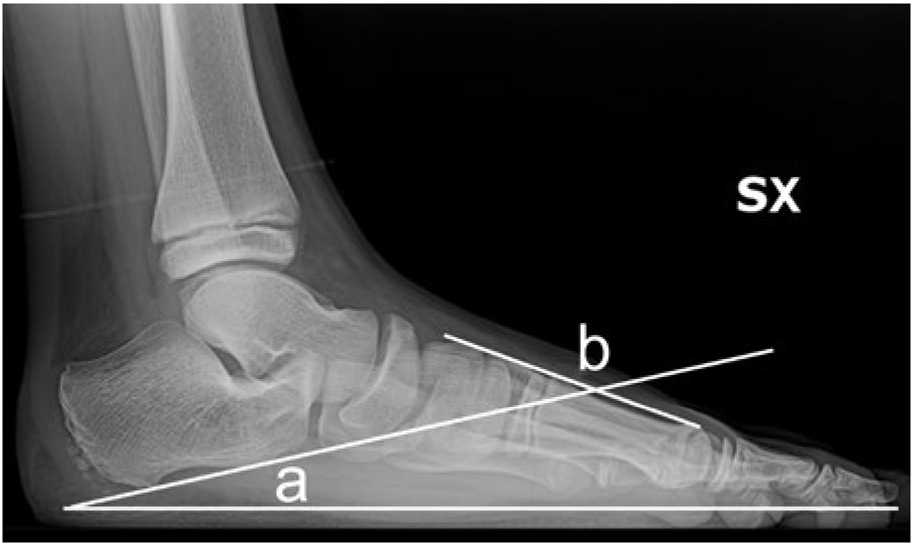

Figure 2. Flatfoot on the lateral view radiography, in a relaxed, bipedal, weight-bearing stance position. Low calcaneal inclination angle (a) with increased value of calcaneal-first metatarsal angle (b).

Talocalcaneal angle

The talocalcaneal angle (Kite's angle) is formed by the intersection of two lines coincident with the longitudinal axes of talus and calcaneus on the horizontal plane. When the talocalcaneal angle is markedly increased, both on the anterior-posterior and lateral radiographs, hindfoot eversion is present.

Calcaneal inclination angle

It is the angle between the inferior surface of the calcaneus and the supporting surface, as assessed on the lateral view radiography (Fig. 2). A lower calcaneal inclination angle indicates a flatter foot, however the proposed normal values refer to the adult population only (range 17.9-25.4° for males and 17.2-23.3° for females).

Calcaneal-first metatarsal angle

It is the angle formed on the lateral view radiography by the prolongation of a line parallel to the inferior surface of the calcaneus above the dorsum of the foot and the dorsal surface of the first metatarsal (Fig. 2). A greater value indicates a flatter foot and the proposed normal range is 128.1-136.1° for males and 129.3-137.4° for females.

Talo-navicular coverage angle

It is formed by the line, drawn on the anterior-posterior view radiography, connecting the anteromedial and the anterolateral extremes of the talar head and the line drawn along the proximal articular surface of the navicular bone. In flatfoot, the talar head is no longer covered by its articulation with the navicular bone, and the talo-navicular coverage angle increases (it may exceed 19.3° in men and 21.7° in woman with flat-arched foot posture).

Paediatric flatfoot

A recent study of children aged 11 to 15 years revealed that there is no association between the degree of foot flatness (as evaluated by the arch index) and motor skills or athletic performance (Tudor *et al.*, 2009). On the contrary, the presence of the supinated, rather then pronated, foot type (as evaluated by the FPI-6) was found to be associated with the increased risk of overuse injury in adult triathletes (Burns *et al.* 2005) and adolescent indoor football players (Cain *et al.*, 2007). However, unrecognized and progressing flatfoot can lead to abnormal structure and strain in the foot, as well as in the leg and lower back region, compromising the functionality of the lower limb. Reasonably, concern about a child's foot posture is a common reason for frequent consultations for an array of health care professionals; among them, sports medicine specialists are often the first to recognize and advise on foot pathology.

The American College of Foot and Ankle Surgeons developed clinical practice guidelines for the diagnosis and treatment of paediatric flatfoot (Harris *et al.*, 2004), which have been adopted by Evans *et al.* (2009) in the paediatric flatfoot clinical care pathway (paediatric flat foot proforma, p-FFP). The diagnosis should aim at the identification of the type of flatfoot:

- symptomatic or asymptomatic;
- flexible (normal arches can be observed in non-weightbearing feet and when standing on tiptoe), which can be physiologic, developmental, i.e. improving with time, or non-physiologic, non-developmental, i.e. progressing with age to a more severe degree of structural deformity;
- rigid (the arch is flattened in both weightbearing and non-weightbearing feet).

Diagnosis can be reached through careful history collection, clinical examination and appropriate imaging. A family history of flatfoot suggests that there may be a similar problem in the child. The presence of associated conditions known to influence the natural history and the severity of paediatric flatfoot, such as obesity, neurological (cerebral palsy or hypotonia) or connective tissue disorders (ligament laxicity, Ehlers-Danlos syndrome), muscular dystrophy and structural abnormalities above the ankle (e.g. rotational deformities, length discrepancy, tibia vara, genu valgum) should be taken into consideration. Subjective symptoms may include postural distortion and pain (occurring usually after bouts of activity), occurring in the foot (typically along its medial side), leg, and knee, and resulting in decreased endurance and voluntary withdrawal from physical activities. The age of symptom onset is also important (rigid flatfoot with calcaneonavicular coalition becomes symptomatic in children aged 8-12, while talocalcaneal coalition may manifest itself at 12-14 years) (Thomets, 2002). Previous trauma may unmask *pes planus*, disclosing associated clumsiness and frequent falling, or it can be the cause of deformity (post-traumatic rigid flatfoot).

Diagnostic observations focus on medial arch height, heel eversion (and its inversion on toe rise), tibial and knee position; observation of the other foot characteristics included in FFI-6 could be a useful tool in the evaluation repeated with age or during follow-up after a treatment. The measurements should include NNHt and RCSP (Evans *et al.*, 2009). Evaluation of the diagnosed flatfoot requires also assessment of the angle of gait (AOG, deviation of the sagittal plane of the foot from the line of progression) and base of gait (the distance between both feet perpendicular to the line of progression) and identification of tender areas. The differential diagnosis of rigid flatfoot should be supported by imaging that indicates the underlying cause (Harris *et al.*, 2004):

- tarsal coalition, i.e. congenital osseous, cartilaginous or fibrous union between tarsal bones, most frequently calcaneonavicular or talocalcaneal bars; findings include the presence of fixed hindfoot valgus, pain and loss of subtalar motion;
- congenital vertical talus (convex *pes valgus*), caused by the abnormal plantar flexion of talus (ankle equinus); it should be detected directly after birth, as it may be associated with genetic syndromes;
- peroneal spastic flatfoot without coalition: a painful foot deformity related to various pathologies (e.g. juvenile chronic arthritis, osteochondral fractures in the hindfoot) or idiopathic (hence, diagnosed by exclusion), in which the spasm of the extrinsic muscles restricts subtalar and ankle motion provoking valgus appearance of the foot and pain during activity;
- iatrogenic or post-traumatic deformity, caused by under- or overcorrection of primary foot deformity and by manipulation or casting of the infant foot.

Concluding remarks

Flatfoot is a well established clinical term and a common diagnosis, however a lack of consensus on the methods of its evaluation and indications for treatment makes it still a controversial topic. The most common form of paediatric flatfoot in sport medicine consulting room, i.e. developmental flexible asymptomatic flatfoot in the children under the age of seven, does not require treatment; children should be periodically observed for possible onset of symptoms or signs of deformity progression and the parents should be reassured. Progression requires reassessment to identify possible underlying disease that should be managed accordingly. In general, patients with non-physiological (progressing) asymptomatic flatfoot may benefit from stretching or orthoses. Symptomatic forms of flexible flatfoot should be treated with activity modification, stretching exercises performed under physical therapist guidance, and orthoses. If the response is not satisfactory, surgical intervention can be considered. The recently proposed guideline (Harris *et al.* 2004) and protocol (Evans *et al.* 2009) may contribute to the standardization of flatfoot management, however the decision making process should be individualised in each case.

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