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A review of the evidence for non-surgical interventions for flexible pediatric flat feet

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The pediatric flat foot is a frequent presentation in clinical practice, a common concern to parents and continues to be debated within professional ranks. As an entity, it is confused by varied classifications, the notion of well-intended prevention and unsubstantiated, if common, treatment. The available prevalence estimates are all limited by variable sampling, assessment measures and age groups and hence result in disparate findings (0.6-77.9%). Consistently, flat foot has been found to normally reduce with age. The normal findings of flat foot *versus* children's age estimates that approximately 45% of preschool children, and 15% of older children (average age 10 years) have flat feet. Few flexible flat feet have been found to be symptomatic. Joint hypermobility and increased weight or obesity may increase flat foot prevalence, independently of age. Most attempts at classification of flat foot morphology include the arch, heel position and foot flexibility. Usual assessment methods are footprint measures, X-rays and visual (scaled) observations. There is no standardized framework from which to evaluate the pediatric flat foot. The pediatric flat foot is often unnecessarily treated, being ill-defined and of uncertain prognosis. Contemporary management of the pediatric flat foot is directed algorithmically within this review, according to pain, age, flexibility; considering gender, weight, and joint hypermobility. When foot orthoses are indicated, inexpensive generic appliances will usually suffice. Customised foot orthoses should be reserved for children with foot pain and arthritis, for unusual morphology, or unresponsive cases. Surgery is rarely indicated for pediatric flat foot (unless rigid) and only at the failure of thorough conservative management. The assessment of the pediatric flatfoot needs to be considered with reference to the epidemiological findings, where there is consensus that pediatric flexible flat foot reduces with age and that most children are asymptomatic. Globally, there is need for a standard by which the pediatric flat foot is assessed classified and managed. Until then, assessment should utilize the available evidence-based management model, the p-FFP Future research needs to evaluate the pediatric flat foot from representative samples, of healthy and known disease-group children prospectively, and using validated assessment instruments. The preliminary findings of the benefits of foot exercises, and discrete investigation into the effects of shoes and footwear use are also warranted.

KEY WORDS: Flatfoot - Child - Orthopedics.

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The pediatric flat foot is a common concern and has long been regarded as a problem, and feared to be potentially disabling. A recent review of the consultation prevalence for musculoskeletal problems found that the foot was the most common region presented in children.[1] Earlier reports have cited flat foot as the most frequent condition seen in pediatric orthopedic clinics.[2, 3] Flat feet have long been associated with pain and disability, and are a concern to parents from a preventative perspective as a part of their children's health and mobility.[4, 5]

Definition of what exactly constitutes a flat

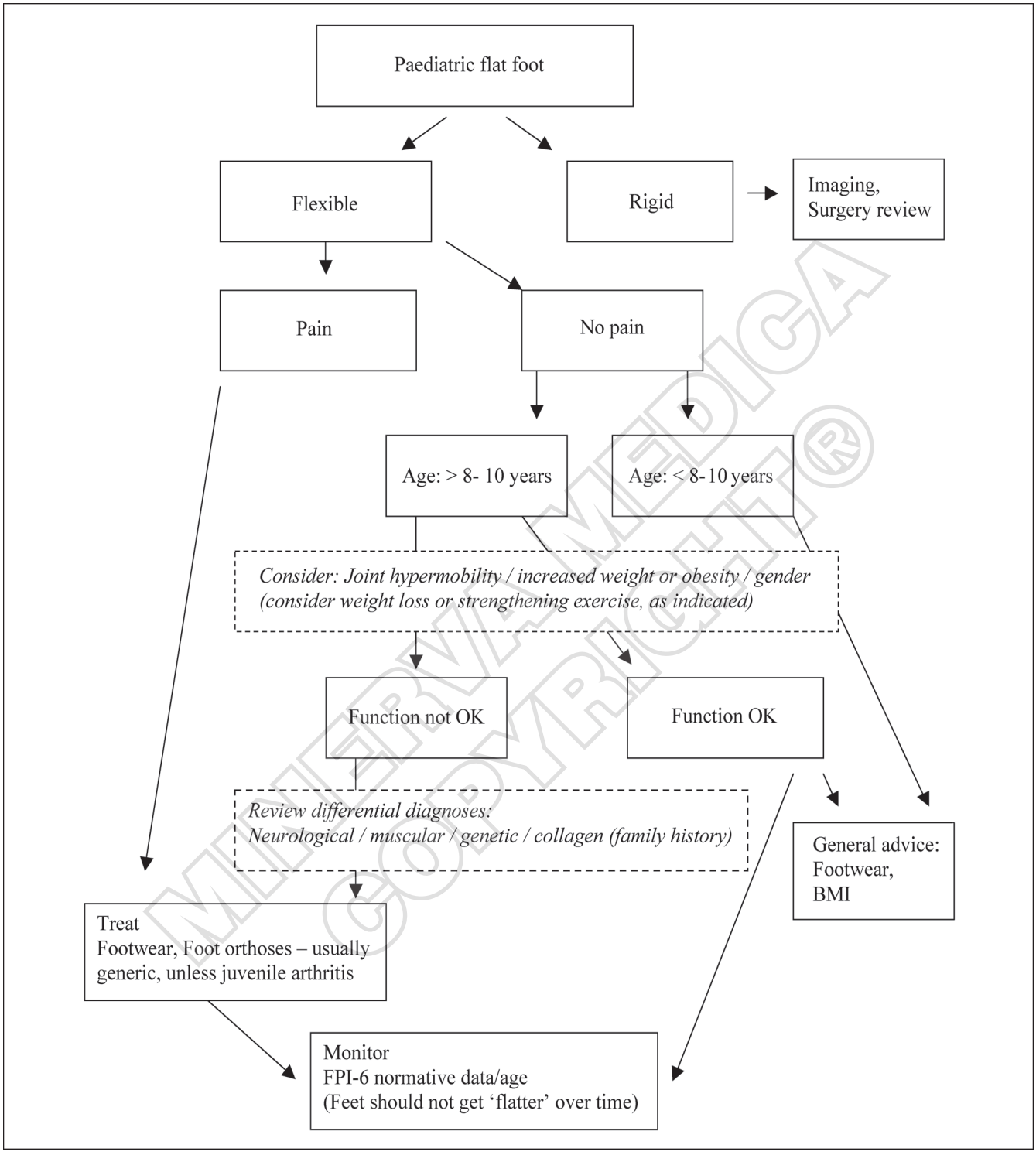

Figure 1.—The algorithmic approach to the management of flexible pediatric flat feet (embellishing the p-FFP framework).

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foot remains surprisingly debatable, given its common presentation.[6, 7] It is widely accepted that a low medial arch and a valgus heel position are consistent attributes.[2, 3, 8] An array of cumbersome synonyms have described flat feet including: pes planus,[9] calcaneovalgus,[10] pes valgus,[11] flexible flat foot,[12] flexible pes planus,[13] planovalgus,[2] postural valgus hindfeet,[14] hypermobile flat foot,[15] pronated foot.[16] The term flat foot is so ensconced within our common parlance that its use is indisputable.

The ill reputation which still dogs flat feet, has historical roots. Ilfeld's expose of military history from the 19th century, indicated that foot symptoms resulted in 30-40% of the US army's medical discharges.[17] It was observed that many of the soldiers who had painful feet, also had flat feet, heralding the assumption that flat feet caused disability. Rigid policy was then developed against flat feet in the armed services. However, the use of simple arch supports was shown to return many recruits with painful flat feet to active service. Whilst it was observed at this time that many soldiers with flat feet were asymptomatic, the association of flat feet with disabling pain and the benefit of arch supports for pain relief was established. This tenet gradually osmosed within wider clinical practice, encompassing the present day, where the presence of flat footed posture has long been described as an abnormality associated with pain and poor gait function.[18] For this reason, many parents are naturally anxious to obtain prophylactic advice and treatment if they suspect that their child may suffer from this condition.

There is no doubt that some flat feet are associated with pain and disability and that orthotic therapy is beneficial is such cases.[19] There is much dispute regarding children with flat feet being potentially hindered.[2, 15, 20-23] There is even more disagreement about the use of foot orthoses in children, particularly when asymptomatic.[24] The notion of prevention has seen children with flat feet treated with foot orthoses in effort to rid them of future disability. However, passionately espoused [21, 25-31] this precept is not substantiated and clinicians continue to differ over the management of children with flat feet.

Whilst there is copious literature addressing the pediatric flat foot, the methodological quality of the research realises a relative paucity from which clinical decisions about the management of pediatric flat foot can be derived. Indeed the summary from a Cochrane Library systematic review states that the evidence from randomised controlled trials is currently too limited to draw definitive conclusions about interventions (non-surgical) for pediatric flat foot.[32]

This review of management of the flexible pediatric flat foot cannot produce definitive nor absolute parameters by which the pediatric foot can be assessed and conclusively managed. It does not fully encompass the management strategies for rigid pediatric flat foot conditions. There is currently not sufficient prospective data to demonstrate which pediatric flat feet require and benefit from which treatments. That said, this review summarises the best available evidence by which clinicians can be advised and researchers directed by algorithmic approach (Figure 1).

Epidemiology

The 15 studies reporting the prevalence of pediatric flat foot are summarized in Table I.[32-93] As can be seen, the prevalence estimates are vastly variable, and range from 0.6-77.9%.[33, 34] From Table I it is clear that there are widely varying age groups, differing assessment methods and ethnicities contributing to such disparate findings. However, within these studies there is also notable concordance when age range is matched. Pfeiffer,[36] Lin,[37] Morley [38] and Rose [8] each studied preschool children (range 2-6 years) and found similar prevalence of flat foot (range 37.5-97%, mean 46.3%). Similarly, El,[3] Bordin,[39] Morley [38] and Jerosch [40] investigated flat foot in children approximating 10 years (range 8-13 years) and found similar prevalence (range 4.0-19.1, mean 14.2%). Rao's large study of 2 300 children in India appears to underestimate flat foot prevalence at both preschool (14.9%) and in older children (2.5%); however, the use of footprints in isolation to assess flat foot also sets this study apart, as does the influence of footwear use.[41] Previous studies which sought flat foot prevalence across the span of childhood years [42, 43] reported prevalence estimates of 2.7-18% (mean 10.4%).

Whilst there are differing prevalence estimates for pediatric flat foot, there is also largely assent in terms of the inverse relationship between prevalence of flat feet as children grow older. This is an important consideration in terms of both natural history and reference to normative values.[2, 44] In common with many epidemiological findings, the estimates of flat

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TABLE I.—*The studies which returned prevalence estimates (range: 0.60-77.9%), reported on children of disparate ages, varying samples and used a range of classifications and assessment methods.*

Author, year	Age of children Country	Sample size	Assessment method	% flat feet
Gould 1989 [34]	11-14 mo, until 5 y USA	125	Physical exam, X-rays, photos	77.9, at 5 years
Pfeiffer 2006 [35]	3-6 y USA	835	Low arch, Valgus heel	44
El 2006 [3]	9.23±1.66 y Turkey	579	Footprints, Arch index	17.2 moderate/severe 82.8 normal/mild
Lin 2001 [36]	2-6 y Taiwan	377	Physical exam, Physical tasks, Gait analysis	2-3 y: 57 3-4 y: 40 4-5 y: 28 5-6 y: 21
Echarri 2003	3-12 y Congo, Spain	1851	Staheli index, Clarke's angle, Chippaux-Smirak index	Most flat at 3-4 y' boys had more flatfeet, flat feet decreased with age
Rao 1992 [41]	4-13 y India	2300	Footprints	6 y: 14.9 13 y: 2.5 Shod vs. unshod children: 8.6 *vs.* 2.8
Rose 1985 [8]	1.9-4.3 y 5-12 y England	237	Physical exam, Footprints, Valgus index	37.5 9.9
Morley 1957 [39]	1-4 y 5-11 y England	451 318	Physical exam, Footprints	Age <18 mo (97%) Age 10 y (4%)
Staheli 1987 [2]	1-70 y USA	882	Footprints, Staheli index	"Arch formed in most children"
Didia 1987 [33]	5-14 y Nigeria	990	Footprints, Footprint contact index II	0.60 bilateral 2.2 unilateral
Widhe 1997 [93]	Newborn-16 y Sweden	0 y-2 401 6 y-121 16 y-108	Physical exam, Gait analysis, Foot pressures	% not reported; 2/3 with flatfeet were boys; flatfeet not associated with overweight subjects
Craxford 1984 [43]	15 mo-13 y England	100	Pedobaragraph	18
Bordin 2001 [38]	8-10 y Italy	243	Photography	16.4
Garcia-Rodriguez 1999 [42]	4-13 y Spain	1181	Footprints	2.7
Jerosch 1998 [40]	10-13 y Germany	345	"Standardized protocol"	19.1

foot prevalence in children is influenced by the varied samples of children examined, the methods of assessment used to assess the foot posture, and the subsequent criteria employed to delineate feet as flat *versus* non flat.

The contemporary works of Pfeiffer and El, where the prevalence of flat feet in preschool and older school age children were examined respectively, are worthy of closer consideration as each reflects the overall findings of prevalence estimates spanning 1957-2006. These studies include methodologies best representing the gamut of all the prevalence studies (Table I) and offer valuable information for clinicians and researchers alike.

Examining the foot posture of young children, Pfeiffer *et al.* determined the prevalence of flexible flat foot in 835 children aged three to six years was found to be 44%, based on observation of a low medial longitudinal arch and valgus heel position.[36] This study also revealed the relevant correlates of age, weight and gender and evaluated the necessity of treatment. In agreement with other prevalence

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studies, a reduction of flat foot was seen with age. It was also observed that boys and overweight or obese children, had a greater tendency for flat foot than girls and normal weight children. Simultaneously the conundrum of physiological as opposed to pathological flat foot was addressed within this study, using the criteria of the German orthopedic association, whereby preschool aged children display flexible flatfoot with a correctable heel position of <20° valgus, whereas a heel valgus position of >20° and/or pain is deemed pathological. Ten percent of the children were being treated with arch supports, yet less than one percent were found to have a pathological flat foot, as stipulated. The unnecessary use and cost of arch supports and corrective shoes is noted, as too is the necessary treatment for children with symptomatic or pathological flat feet as defined by this study's criteria.[36]

The study of 579 school children (mean age 9.23±1.66 years) to analyse the foot arch morphology and associated factors by El *et al.*, provided further valuable information about pediatric flat foot.[3] Using the arch index to evaluate footprints, the children were also assessed for heel position and foot progression angle (again from footprints). In addition generalized joint laxity was assessed using Beighton's nine-point assessment method.[45] This study evaluated 17.2% of children having moderate and severe flexible flatfoot from elevated arch index and heel valgus results. Generalised hypermobility was found in 25% of children and accorded with flat foot, as 27.6% of hypermobile children displayed flat foot in comparision with 13.4% of non-hypermobile children. Whilst within a discrete age range, a significant negative correlation was found between flat foot and age, hypermobility and age, whilst heel valgus and age correlated positively.

An essential finding from Pfeiffer and El's studies, with large consensus from earlier prevalence investigations, is that flexible pediatric flat foot is a normal finding in approximately half or more young children from walking age and that this prevalence is seen to reduce (by approximately 50%) as children grow up. Positive correlates with increased findings of pediatric flat foot include gender (with boys more implicated), increased weight and increased generalized joint hypermobility. These epidemiological parameters provide helpful direction for clinical assessment and help to define warranted, as opposed to unnecessary, treatment.

A limitation of all of the prevalence studies, is the sampling methodology. No study has sourced a random sample from a population of interest, nor has the sample size been calculated with respect to representing the population concerned. All studies to date have employed convenience samples, with some from the wider community, *e.g.*, schools, but others from more inherently biased sources, *e.g.*, clinics, hospitals.

Foot development

The lower limb buds first appear between three and five embryonic weeks, and are positioned slightly lateral to the lumbar-sacral myotomes.[46] The foot develops from condensed mesenchyme which projects through the adjacent estoderm to form the foot template or *anlage*. Much differentiation of the embryonic tissues occurs to form the cartilaginous, osseous, vascular and neural components of the eventual infant foot. The average length of the foot at term gestation is 7.6 cm (range 7.1-8.7 cm).[46] Foot growth continues to be very rapid until five years of age, slowing toward the skeletal maturity of the feet, which occurs on average by age 12 years in girls and by age 14 years in boys.[47] From birth until approximately eight years of age, there are a number of changes in alignment and mobility which occur due to both osseous modeling and growth. Normal neuromotor development is crucial to the dynamic changes which need to occur to convert the very plastic infant skeleton to a more static form.[48] The primary bony attribute of the young child's foot which renders it "flat" when weight-bearing is the varus position of the heel (converts to valgus with stance). The soft tissue allies of this developmental flat foot posture are ligament laxity,[49] muscle strength muscle tone.[48] Babies born prematurely are more likely to be hypotonic and "floppy babies" with developmental delays.[50]

Etiology and associated issues

Etiology

According to Tachdjian's time-honoured text [49] "flat foot" is a loose generic term used to describe any condition in which the longitudinal foot arch is

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abnormally low or absent. Further, it is asserted that the simplicity of this term may be deceptive, and result in faulty diagnosis of a large number of children with normal feet that appear flat. It is a quarter of a century ago that Tachdjian, like Rose [8] acknowledged the need for clear definition and classification of flat foot. In the 21st century this situation remains and stymies clinical practice and research globally. There is need for a standardized framework from which to evaluate the pediatric flat foot.

Most children's flat feet are not painful.[4, 5, 18, 32, 42, 47, 51-57] Symptomatic flat feet, rigid flat feet, flat feet which are progressive, or more subtle signs of withdrawal from physical activity are not normal and require detailed examination and careful diagnosis.[58, 59]

The factors which determine young children's feet to be normally flat can be usefully categorized. From the literature it can be fairly ascertained that the markers of increased susceptibility for physiological flat foot may include: age, gender, weight, hypermobility, footwear use. Thus young boys who are overweight/obese, more hypermobile and consistently shod from an early age would, as a cohort be expected to have flatter feet than older girls who exhibit normal, joint mobility and barefoot activity. Clearly these polarized positions will be intersected by the many variations which constitute normal foot development in children.

Conversely, the non-physiological pediatric flat foot markers may include factors which fall within four main subgroups: neurological (*e.g.*, cerebral palsy, hypotonia); muscular (*e.g.*, muscular dystrophy or atrophy); genetic (*e.g.*, osteogenesis imperfecta, Marfan's or Down's syndromes); collagen (*e.g.*, ligament laxity, Ehler's Danlos). Other considerations may include trauma, orthopedic entities (*e.g.*, tarsal coalitions, ankle equinus, calcaneo-valgus, os tibiale externum) or familial predisposition.[6, 7, 47, 54, 59]

As previously mentioned, children with painful or rigid flat feet are never benignly considered as 'normal', and require full assessment and the necessary ameliorative management.

Associated issues

In addition to age, many extraneous issues have been correlated with the pediatric flat foot. Overweight or obesity, joint hypermobility and, to a lesser extent, strength have all been cited as factors which may contribute to a child's flat foot posture.

Obesity

Many studies have investigated the correlation between children's foot posture and body weight.[35, 36, 60-62] All agree that foot morphology is "flatter" in children who are overweight or obese than in normal weight controls. Dowling and Villarroya used footprints based measures (Chippaux-Smirak index) in finding significant correlation between increased body weight and flat foot in adolescent children.[61, 62] Pfeiffer, Mickle and Lin investigated preschool children using rear foot angle, footprints (arch index) and gait analysis and each found significant differences in the prevalence of flat foot in overweight (51%), obese (62%) and normal weight (42%) children.[35] It is notable that the studies associating flat foot with overweight and obesity, have exclusively employed footprint measures s as the objective foot posture assessment, which may confound foot adiposity with overt flat feet.[63]

Hypermobility

Flexible flat foot has been considered to be a manifestation of a constitutional laxity affecting all ligaments. Generalised joint laxity is easily evaluated using the Beighton scale, where a score of five or more on a nine point scale indicates hypermobility.[45] El's study of 146 nine-year-old children found flexible flatfoot in 27.6% of hypermobile children and in 13.4% of non-hypermobile children.[3] Lin found increased joint laxity scores in children with moderate and severe flatfeet as opposed to those with normal or mild flatfeet.[37] Joint hypermobility is often familial, more common in girls, reduces with age and a common association in musculo-skeletal joint pain.[48, 64] The Beighton scale has been found to correlate well with the lower limb assessment score, a reliable 12-point scale which is specific for lower limb hypermobility.[65]

Strength and function

Highly significant and inverse associations have been found between measures of foot strength and motor function in healthy children aged two to four years.[66] In addition, adequate ankle dorsiflexion has been found to be the strong independent correlate of foot and ankle strength in young children.[67]

Using the arch index to determine foot posture in

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218 adolescents and motor skill tests, no significant correlations were found between arch height and the children's extrapolated athletic performance.[68] By way of contrast, in a case-controlled study of 52 children age nine to 12 years, kinematic evaluation showed reduced arch and forefoot supination in children with flatter feet versus normal foot type controls.[69]

Diagnosis

The definition of flat feet has not been helped by the varying assessment techniques employed to delineate various aspects of these structures as shown in Table I viz. physical examination/observation (largely of the medial longitudinal arch and heel angle), photography, footprints, gait analysis/plantar pressures, pedobarograph measures. Extracted from the preliminary science of foot biomechanics, clinical measures of the feet have been an area of great dissent amongst both clinicians and researchers. The last two to three decades have seen investigation of clinical foot measures by evaluating the basic measurement principles of reliability and validity.[70-72] In general the reliability of these measures is poor. Very little research has addressed the use of these measures for children's feet specifically, despite these being widely used for pediatric assessments.

Most attempts at classification or defining the flat foot have focussed on three aspects: arch height, heel eversion angle and whether the flat foot structure is rigid or flexible. Most classifications have consisted of footprint assessment, X-rays and visual observation.

Arch

Understandably, much attention has been paid to the medial longitudinal arch of the foot when addressing foot posture. It is well documented that the normal infant's foot begins as a flat foot with the medial longitudinal arch developing during childhood.[2, 34, 41, 73] It is also accepted that the flatness of normal children's feet and their age are inversely proportioned.[52] The arch has been assessed using footprints,[2] radiographic imaging, pedotopography [i 34] and clinical or anthropometric measurements.[34, 74] Staheli [2] devised an arch index from footprints in 441 subjects aged from one to 80 years. Staheli's arch index was calculated by measuring the width of the footprint arch and the width of the footprint heel and dividing the arch measure by the heel measure. Arch index results ranged broadly as follows: in infancy 0.70-1.35 and 0.30-1.0 after childhood, indicating a decline in foot print arch width with increasing age and surmised by the authors to be indicative of increasing arch height during childhood. Gould's study (quasi-RCT) looked specifically at the development of the child's medial longitudinal arch in subjects aged 11 months to five years.[34] The children were studied for four years with X-ray, clinical and photographic examinations each year. This study found that medial longitudinal arch development was rapid in the first five years of age and was faster until three years of age if arch support footwear was used. It must be noted that X-ray angles were used to categorise the feet as having "normal, slightly flat, moderate" arches, which must have been difficult when using radiographs of such young incompletely ossified feet. Saltzman [74] performed clinical and radiographic assessments in adults in an effort to validate clinical measures of the medial longitudinal arch. The best anthropometric parameter to characterise medial longitudinal arch structure was found to be a ratio of navicular height to foot length.

Heel angle

Heel valgus [14] is generally accepted as a normal finding in young, newly walking children and is expected to reduce with age. The valgus angle of the heel has been repeatedly used as a criterion for determining the postural status of the child's foot.[75] Whilst originating in the orthopedic literature,[76] there has been a strongly held view within the podiatric community that a vertical heel (as assessed by its bisection) is optimal for sound biomechanical functioning of the foot.[16, 27] The basis for this principle comes from the attempts of Root *et al.*[16, 77] to define all motion within the foot in reference to the three cardinal body planes. More recent research has challenged the validity of the Root model and suggested alternative methods.[71, 78-81] A study investigating the rear foot angle in 150 children aged from six to 16 years [82] found the average rear foot angle for all children was four degrees valgus (ranging from zero to nine degrees valgus).

[i]Observation of the weight-bearing foot surface done with photography.

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TABLE II. — *The scales and indices frequently used to assess the paediatric flat foot, yet not all have been developed in pediatric subjects. Reliability has been variably assessed. These scales are all based upon static footprints, or visual observations.*

Scale Author, Year	Reliability study subjects Technique	Level of reliability
Valgus Index Rose, 1985 [8]	Flat foot in children Footprint angles	Intra-rater 11% error – 3 repeats 8% error – 5 repeats
The Arch Index Cavanagh, 1987 [104]	Adults Footprint angles –compares midfoot to footprint	Intra-rater r=0.94
Staheli Arch Index Staheli, 1987 [2]	Adults Footprint angles –compares midfoot to rearfoot	Intra-rater r=0.50
Visual Assessment Dahle, 1991 [81]	Athletes 13-18 years 5 observed criteria	Inter-rater κ=0.72
Chippaux-Smirak Index Forriol, 1990 [93]	Adults Footprint angles – compares midfoot to forefoot	Intra-rater r=0.60
Foot Posture Index Redmond, 2006 [101]	Adults 6 observed criteria	Intra-rater Cronbach's α=0.84
p-FFP Evans, 2009 [103]	Children History, examination and management proforma	Inter-rater ICC=0.71

Foot flexibility

The literature is replete with arguments about what constitutes a physiological flat foot versus a pathological (rigid) flat foot [14, 83] with Jack's great toe extension test [ii] used as the delineating factor.[2, 8, 51, 84-86] Bleck and Berzins classified such flexible flat feet as having a plantarflexed talus in static stance, which they regarded as the central feature of this deformity.[11] Rose also includes the great toe extension test in the diagnosis of flat foot,[8] and Staheli [2] was emphatic about the distinction between pathologic (rigid) flat feet and physiologic (flexible) flat feet. The significance of the flexible flat foot continues to be the topic of much contention.[9, 42, 86-89] Numerous authors have linked flat feet and growing pains in children, yet the most substantive evidence negates this claim.[90]

Footprints

Footprints have been used somewhat intuitively to assess the foot's posture, the effects of orthotic intervention [28, 52, 91] and especially in the study of flat feet in various populations.[2, 8, 9, 28, 33, 41, 52, 73, 86, 89, 91, 92] Harris and Beath's classic study prior to World War II [92] made popular this method of flat foot classification from which Rose developed the valgus index [8] as an early quantitative measure of flat feet (Table II).[92-104] The footprint has continued to be included as a surrogate indicator of arch height and has formed the basis of static plantar pressure measurement using the pedobarograph,[43] foot-ground pressure patterns [10] and dynamic plantar pressure systems.[94] Whether or not footprints reflect the real morphology of the medial longitudinal arch is controversial.[94, 95] Kanatli's [89] study of six-year-old children attempted to validate the footprint arch index by correlation with x-ray images. Whilst statistically significant correlations were found, the use of the arch index and the methodology of this study mean that findings are questionably conclusive. As has already been mentioned, the use of footprint measures may be confounding foot adiposity with foot posture.[63]

X-rays

Rose,[8] referring to the use of X-rays for diagnosis of flat foot in children, stated: "radiographs are not helpful, being flat images of a three-dimensional situation [… and that] diagnostic lines and angles must be treated with great caution since they may well show the same angle changed by viewing in a different axis. In addition, the ossific centers for all the foot bones do not appear until four years of age, and it is not until the age of 9 or 10 that features such as sustentaculum tali can be seen".

Despite this observation, there has continued to be radiographic evaluation in many studies attempting to address children's foot posture.[11, 15, 20, 28, 89]

[ii] To perform Jack's great toe extension test, the great toe is manually dorsiflexed whilst the child is standing. If the medial longitudinal arch is seen to rise, the foot is deemed a flexible flat foot. If the arch remains static, this test designates this a rigid flat foot.

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Staheli [2] suggests that X-rays are only appropriate to determine the aetiology of rigid (pathologic) flat feet and that these views should be taken in stance. Wenger's randomised controlled trial (and similarly Gould's quasi-RCT [34]) to assess the effect of shoes and inserts on children's skeletal structures (aged one to six years) involved x-ray analysis at entry and every six months for a three year period to see whether treatment group foot X-rays changed *versus* the control group.[97] These findings showed no difference in foot morphology between groups at the completion of the study.

Observation and the development of clinical measures

Visual appearance of the foot has been the basis of all other observations and has resulted in the development of quantitative measures. As previously mentioned, the arch, heel, ability of the foot to flex and form an arch and footprints have all been aspects observed and judged as constituents of the flat foot structure. X-rays have enabled an extension of visual observation, if limited to static, osseous, two-plane images. Rose promoted the concept of subtalar joint stability and also attempted one of the first measures of foot posture, the valgus index.[8] Whilst based upon a footprint, the valgus index was the first measure to focus upon the rear of the heel and preceded the clinical measures developed by Root.[16]

A number of observational assessment scales have been developed to try and address the issue of the poor reliability of foot measures. Most have included scaled observations in all three cardinal planes.[8, 81, 98-100] Most recent has been the development of the Foot Posture Index for which normative values have now been compiled [63] (Table II).

Foot Posture Index (FPI-6)

As described by Redmond,[101] the Foot Posture Index consists of six specific criteria: talar head palpation, calcaneal frontal plane position, supra and infra lateral malleolar curvature, prominence of sustentaculum tali, congruence of medial longitudinal arch, abduction/adduction of the forefoot on the rearfoot. The FPI-6 is an extended version of the visual assessment scale of foot type developed by Dahle,[81] which consisted of five similar criteria.

Flat Foot Proforma (FFP) and pediatric Flat Foot Proforma (p-FFP)

Developed in response to the clinical dilemma of pediatric flat foot assessment, the FFP is a composite tool which combines clinical guidelines,[54] systematic review [32] and investigated measures used to examine pediatric foot posture [102, 103] into an assessment framework which directs intervention.[59] The p-FFP is the shorter revised version, with tested inter-rater reliability of 0.71 [105] (Figure 2). Spirited debate followed the development of the initial FFP, which in essence recommends a three-pronged approach to direct management: 1) symptomatic flexible flat feet is treated (foot orthoses, in-shoe wedges, stretching exercises); 2) asymptomatic, non-developmental flat feet are largely monitored; 3) asymptomatic, developmental flat feet are left alone (being recognized as normal). The main concerns of the protagonists held strongly to the unsubstantiated view that children's flat feet are potentially a (painful) problem and that preventative measures should be employed.[106-108]

Non-surgical management

Conservative, or non-surgical, intervention for pediatric flat foot has primarily involved in-shoe foot orthoses, although in times past, calipers and orthopedic footwear also featured. Footwear is the first external influence of foot posture and may, with assiduous selection, be of benefit. Exercise for flat feet, in the form of barefoot time and also prescribed activities (*e.g.*, picking up marbles) has also been used.[109] How necessary the role of any non-surgical intervention may be for the typical, flexible pediatric flatfoot remains controversial.

Historically it was observed that painful feet were often "flat" or that people with painful feet had a lowered medial longitudinal arch and everted (or "valgus") heel position. Those possessing and physically limited by their flat feet were, in effect, "weaker" than their better footed counterparts being less able to walk or run distances or to work efficiently. In an effort to "strengthen" those afflicted with flat feet, various arch supports were developed.[110, 111] Whilst these appliances have changed in style and materials, the basic principle is still incorporated into current orthotic therapy.

A recent critical review addressed the efficacy of non-surgical interventions in the management of

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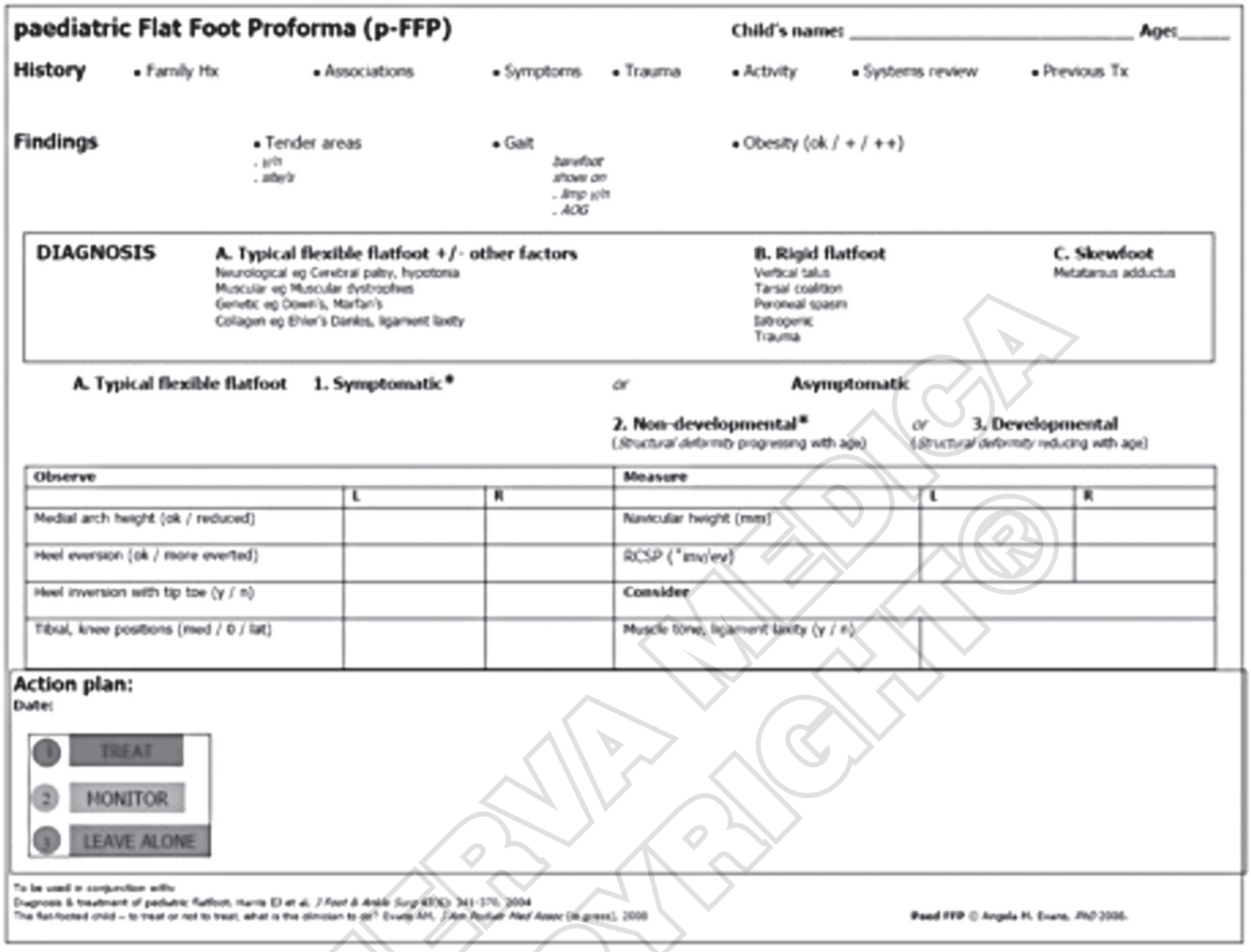

Figure 2.—The pediatric flat foot proforma (p-FFP) is an evidence-based, pragmatic and composite assessment for the pediatric flat foot, which directs intervention.

pediatric flexible flat foot using a validated quality index (Mackenzie AJ, Rome K, Evans AM. A critical review of the efficacy of non-surgical interventions in the management of pediatric flexible flat foot. manuscript submitted for publication 2010). Thirteen articles spanning forty years returned an average quality score of 35% (range: 13-81%) (Table III).[110-113] Three of the studies had no control or another intervention group against which to compare the effect of the specific foot orthoses being used.[15, 25, 30] The methodological limitations common to all the studies were: subject sampling not being representative of the population; study participants not blinded to the intervention; failure to use valid and reliable measures for the outcomes; and lack of concealment of the randomized intervention from subjects and staff. The follow-up periods ranged from one to 80 months, subject sample sizes ranged from eight to 637 children, and the recruitment age ranged from seven to 168 months. Various methods of diagnosing flat foot were used, with clinical observation of the arch being the most frequent. All studies included foot orthoses (varied) and footwear (with or without modification) as the intervention. Riccio,[112] in isolation, evaluated the difference between a rehabilitative therapy programme and foot orthoses. Radiographic parameters

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TABLE III.—*Study designs, outcome measures and reported findings of non-surgical interventions for pediatric flat foot.*

Author (date)	Age of subjects (range/years)	N. of subjects Start/ Follow-up	Study design	Outcome measures	Results
Riccio *et al.* (2009) [110]	1.9-5 years	637 Group 1: 300 Group 2: 337	Cohort	• Viladot footprints	• Rehabilitative treatment more effective that insoles in improving foot posture
Whitford and Esterman (2007) [57]	7-11 years	178 *178/160*	RCT	• Gross motor efficiency • Self perception • Exercise efficiency • Pain	• No difference between groups (NS)
Selby-Silverstein *et al.* (2001) [111]	3-6 years	26 16 DS, 10 control	Cross-sectional	• Heel eversion • Gait variables • Ankle moment • Walking speed • Sneaker prints • Center of pressure • Transverse plane foot angles	• Reduced RCSP in Down's syndrome comparing barefoot and foot orthoses (P<0.001)
Leung, Mak and Evans (1998) [113]	4-11 years	8	Cross-sectional	• Kinetic and kinematic 2-D Data	• No effect on vertical force
Jay *et al.* (1995) [25]	20 months-14 years	50	Cross-sectional	• RCSP • NCSP	• Improvement in RCSP with and without DSIS (P<0.0001) • Mean decrease in RCSP of 6º
Capasso (1993) [28]	2.1-8.3 years	Group 1: 21 (15% of 138 screened) Group 2: 30	Non-RCT	• Treatment ceased when Grade II footprint reached • Convex medial border • Valgus hindfoot • Jack's test • Great toe nail alignment • Grade III footprint • Drop of patella line medial to great toe • Tiptoe standing • Footprint: Isthmus-metatarsal position; Arch Index; hindfoot axis • Radiographs 1. Meary-Tomeno line 2. Costa-Bertani angle 3. Pisani & Garneri angles 4. Kite angle.	• Group 1 had the largest improvement across all parameters. • Results stated to be highly statistically, but significant, but only percent values were reported and some values are missing
Gould (1989) [34]	11-14 months	125 *125/52*	Q-RCT	• Clinical examination • Pedotopography • X-rays at age 5 years	• Foot arch developed in all groups by age 5 years • Shoe 2 – arch development earlier than other groups • Shoe 3 no difference • Shoe 4 – poorest compliance; no difference
Wenger et al. (1989) [56]	1-6 years	129 *129/98*	RCT	• X-rays	• All groups showed arch development/time • No difference between groups
Valmassy and Terrafranca (1986) [114]	7 months -4.5 years	20	Cross-sectional	• RCSP	• Reduction of calcaneal eversion
Penneau *et al.* (1982) [112]	1.5-4.5 years	10	Cross-sectional	• X-rays	• No difference between groups (NS)
Bordelon (1980) [15]	3-9 years	22	Case-series	• X-rays - Lateral talo-metatarsal angle	• Correction at about 5º per year or 0.41º per month
Bleck and Berzins (1977) [11]	1-12 years	71	Non-RCT	• X-rays	• 79% improved
Mereday, Clyde and Lusskin (1972) [30]	3.5-12.5 years	10	Case series	• Calcaneal bisection angle • MLA height (of x-rays) • X-rays • Pain • Comfort & function	• Immediate correction whilst wearing insert (not statistically evaluated) • No difference in X-ray angles immediately or at follow up. • Pain absolved with FO use

* DS: Down's syndrome; * DSIS: dynamic stabilizing insole system; * FO: foot orthoses; * UCBL: University of California Biomechanics Laboratory (cupped).

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TABLE IV.—*Summary of the findings of the randomized controlled trials investigating the use of footwear and foot orthoses in children.*

	Wenger, 1989 [56]	Gould, 1989 [34]	Powell, 2005 [114]	Whitford, 2007 [57]
Study design	RCT	Quasi-RCT	RCT	RCT
Number of subjects (start/end)	129/98	125/52	40	178/160
Age (years)	1-6	11-14 mo-5	5-19	7-11
Condition	Flexible flatfeet	Normal toddlers	Juvenile arthritis, Foot pain for 1 - 24 months	'Flexible excessive pronation'
Trial groups	Shoe Helfet heel cups UCBL orthoses Control	Shoes with arch cookies Orthopedic shoes with counters, shanks, Thomas heels, wedges Shoes with thin arch support Control (shoes)	Athletic shoes Neoprene insoles Custom orthoses	Generic orthoses Custom orthoses Control
Outcome measures	X-rays	X-rays Clinical exam Photos	Pediatric pain Q, Timed walking, Foot function index, Ped QoL (physical)	Motor skills, Physical activity, Self-perception
Findings	No significant difference between groups	Arch development proceeded across all groups evenly, although faster in first two years with arch cookies	Orthoses group showed significant improvement in: pain, function, QoL	No significant difference between groups

were the most frequent of the varying outcome parameters reported.[15, 28, 34, 56] Other outcome measures included: static foot posture; kinetics and kinematics of gait; pain and function; and self-perception.

Radiographs

Seven studies used x-rays to evaluate the effects of interventions on skeletal alignment of the foot with the effects being evaluated immediately, over time or both. Two studies investigated the immediate effect of footwear, wedges and foot orthoses on radiographic parameters and found either a non-significant difference between the groups or that the between group difference was minimal. All studies evaluating the effect of interventions over time found an improvement in radiographic parameters. The results of Capasso *et al.*[28] favored the group wearing the dynamic varus foot orthoses *versus* the simple insoles. Of the seven radiographic studies only one RCT [56] and one Q-RCT [34] investigated the difference between the groups over time and found no significant differences (Table IV).[111-115]

Static Foot Posture

The clinical assessment of static foot posture was reported as an outcome measure in six studies. The majority used the resting calcaneal stance position (RCSP) as the method of evaluation,[25, 28, 30, 114, 115] although Riccio [112] only used footprints. Capasso [28] evaluated RCSP, the medial border of the foot, Jack's test, the formation of the arch on tip toes, great toe alignment, and patella position.

Mereday [30] measured the medial longitudinal arch height.

Four studies evaluated the immediate effect of interventions on the RCSP of the supported foot and found an improvement.[25, 30, 114, 115]

A significant improvement was found with the dynamic stabilizing insole system foot orthoses [25] and also after adjusting customised foot orthoses to correct the RCSP to vertical.[114]

Although shoes and triplanar wedges improved the position of the RCSP in most subjects, the significance of this improvement was not investigated.[115] Two studies observed the effect of foot orthoses on the RCSP over time and variably found improvement.[28, 30]

Capasso's study found greater improvement in the RCSP with a varus insole *versus* a traditional insert, whilst Mereday's [30] case series found the inconclusive trend of improvement with the UCBL orthoses (Table V).

Capasso [28] and Riccio [112] used footprint analysis to evaluate the effect of different forms of foot orthoses

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TABLE V.—*Foot orthoses (FO) vary in design and description. Terminology used in the clinical setting and the evidence-base includes accommodative, functional, over-the-counter, pre-fabricated, prescription and functional FOs.*

Authors	Foot orthoses	Description
Whitford, [57] Penneau [112]	Over-the-counter	Fabricated from a generic foot cast.
Whitford,[57] Selby-Silverstein,[111] Jay,[95] Penneau,[112] Bordelon[15]	Custom-made	Fabricated from measurements and casts of individual patient's feet
Leung,[113] Wenger,[12] Penneau,[112] Scharer,[128] Mereday [30]	UCBL (University California Biomechanics Laboratory	A maximum-control foot orthoses with a moulded heel cup which holds the heel in a vertical position. The UCBL also controls the medial arch and the lateral border of the forefoot.
Capasso [28]	Dynamic heel cup	A customised heel cup with a medial wedge positioning the heel 5° inverted. An insole within the heel cup further inverted the heel, but pronated the forefoot.
Gould [34]	Thomas heel	Fixed to the sole of the shoe and comprises an anterior-medial extension to the normal shoe heel to provide additional longitudinal arch support. This extension may be of variable length, depending on the extent of the support required, and its effect may be augmented further by a medial wedge.
Gould,[34] Valmassy,[112] Penneau [112]	Medial heel wedge	A medial heel wedge is posted within the shoe to stabilize the rearfoot. Various forms are used.
Wenger,[12] Scharer,[128]	Helfet heel cup	A heel cup that extends from the heel to metatarsal heads. Stabilises the heel, subtalar and mid-tarsal joints.
Riccio,[110] Capasso [28]	Simple insole	Constructed with a flat base material to which various pads may be added. The pads apply corrective or supportive forces to the plantar surface of the foot.
Gould [34]	Longitudinal arch support	Moulded devices which follow the plantar contours of the foot. These supports reduce increased plantar pressures by spreading the load across a larger area of the plantar surface. Bespoke devices which are fabricated from a cast of the foot
Jay [25]	DSIS	'Dynamic stabilising innersole system' that inverts the calcaneus

and rehabilitative exercises, both showing improvement over time, although neither study investigated the statistical difference between groups.

One case series evaluated the effect of foot orthoses on the medial longitudinal arch height.[30] This study used photographs of the foot to calculate the angle along the arch. Results indicated an immediate average improvement when standing on the foot orthoses, although no further analysis was performed.

Multiple other parameters were evaluated by Capasso [28] who found the dynamic varus heel cup improved the contour of the medial border of the foot, Jack's test, formation of the arch when standing on tip toes, great toe alignment, and patella position. There was, however, no statistical comparison made between the groups.

Foot kinetics and kinematics

Selby-Silverstein's [114] study investigated subjects with Down's syndrome in comparison to a control group. A significant decrease in foot abduction during gait was also found and in addition Leung [116] found reduced calcaneal eversion throughout gait, excepting heel strike. Leung also found significant reduction in the rearfoot angle, between the calcaneus and the leg. This angle also significantly increased at the point of maximum eversion of the calcaneus. There were no differences in vertical force or heel eversion at heel strike, indicating that the foot orthoses did not decrease shock absorption.

Pain and function

Two studies have evaluated the effect of foot orthoses on pain. Whitford's [57] randomized controlled trial results indicated a significant improvement over time for pain, but no significant difference between the groups. Mereday [30] found that all of the six of ten subjects in their study with pain prior to wearing UCBL foot orthoses, were pain free during the two year trial.

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Whitford [57] also compared the effects of interventions on gross motor efficiency and exercise efficiency. Gross motor efficiency was assessed by running speed and agility, balance, coordination and strength. Exercise efficiency was measured by a shuttle run test, predictive of maximal oxygen uptake. Similarly to the results for pain, there was a small statistically significant change (not clinically significant) over time for both functional outcomes, but no significant changes between the treatment groups.

Relevant here, are the randomized controlled trial results from Powell's study which evaluated three interventions (athletic shoes, neoprene insoles, customized foot orthoses) in 40 children ages five to 19 years with juvenile arthritis (Table IV). All children presented with chronic foot pain. Using the outcome measures of: pediatric pain questionnaire, timed walking trials, the pain and function domains from the foot function index and the physical domain from the pediatric quality of life questionnaire, there was significant improvement in both pain and function for the children who received the customized foot orthoses.[117]

Self-perception

Self-perception was only evaluated by Whitford [57] and results indicated a significant change over time for scholastic competence, social acceptance and athletic competence, but no significant difference between the groups. There was no significant change over time or between the groups for physical appearance, behavioural conduct and global self-worth.

Surgical intervention

Surgical management of flexible pediatric flatfeet has been debated in a number of roundtable discussions and publications.[6, 54, 118-121] The consensus of opinion suggests that if conservative methods have failed, and the child does not have relief of symptoms, an algorithmic approach for surgery is indicated.[6] Kwon and Myerson [119] suggested that when faced with flexible pediatric flatfeet in children, the treating surgeon should use a systematic method for evaluation to distinguish normal variation from true pathology. Blitz [6] further reported that the purpose of any surgical intervention is to improve the overall foot alignment, and reduce or eliminate pain. Further, that flatfoot must be considered on a case-by-case basis, and various factors play a role in the surgical plan. Zeifang [120] also stated, since no well accepted objective parameters that can be used as indications for surgical correction are available, treatment must be individualised.

The surgical procedures that have been described for flexible flatfoot are reconstructive arthrodesis (extra-articular), osteotomy, and/or arthroereisis.[6] While medial column or rearfoot arthrodesis is indicated with skeletal maturity (or when the growth plates are near closed in the subtalar joint), osteotomy and arthroereisis are the two principal options for children.[122] Blitz [6] suggested that flatfoot procedure selection often involves a combination of these types of procedures, and that the pathomechanics and planal dominance (frontal, sagittal and transverse) of each individual foot is critically considered when planning a strategic surgical intervention.

Arthroereisis implants

The current procedure calls for placing an implant (metallic or absorbable) into the rearfoot between the talus and calcaneus.[54] The purpose of the implant is to be "well-seated" within the sinus tarsi, thus preventing collapse of this space (*i.e.*, pronation). Blitz [6] reported that a distinct advantage of the arthroereisis procedure in the pediatric population is that the implant provides structural realignment of the rearfoot complex during skeletal growth, which may become a permanent correction as the child reaches skeletal maturity.

Giannini [121] reported on the evaluation of the correction of bilateral flexible flatfoot in 21 children (aged between 8-15 years) by undertaking an arthroereisis of the subtalar joint with use of a bioreabsorbable implant. The authors concluded by stating that: "extra-articular arthroereisis with use of a bioreabsorbable implant in the sinus tarsi was simple and effective in correcting functional flexible flatfoot. Surgery performed during growth provides an optimal and lasting correction of the deformity, restoring the talocalcaneal alignment with remodelling of the subtalar joint. This correction improves the biomechanics to prevent problems caused by persistent pronation of the foot".

Nelson [123] reported on a case series of 37 children (67 feet) who underwent a Maxwell Brancheau Ar-

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throereisis (MBA) implant as an isolated procedure. The average follow-up was 18.4 months. While this study reported various improvements in anatomical measurements, there was no data reported on improvement in symptoms or other functional outcomes from flatfoot deformity. Vedantam [124] reported on a case series of 78 children (140 feet) with neuromuscular disease who underwent subtalar arthroereisis with a Smith Subtalar Arthroereisis implant (STA-Peg). The stem of this implant was placed into the calcaneus with the collar abutting the inferior surface of the lateral aspect of the talus, thus limiting motion. All but five of the children had additional procedures to balance the foot. Satisfactory results were reported in 96.4% of the children, although the contribution of the STA-Peg cannot be isolated as the implantation was combined with muscle-balancing procedures.

Cicchinelli [125] reported on radiographic outcomes in a retrospective analysis of 28 feet in 20 children treated with subtalar arthroereisis combined with gastrocnemius recession, or with subtalar arthroereisis combined with gastrocnemius recession and medial column reconstruction. The authors report that gastrocnemius recession had a notable effect on correction of transverse plane deformity when used as an adjunct to subtalar arthroereisis and gastrocnemius recession.[125]

Scher [126] described two cases of extensive implant reaction in two children two years after STA-peg procedures and tendo-Achilles lengthening when performed for bilateral painful flatfoot deformities. The children had minimal subtalar motion and pain at the sinus tarsi. Radiographs demonstrated surgical defects in the calcaneus. After failure of conservative management, implants were removed with good relief of pain. The authors stated that: "complications reported in the literature are common and wide ranging. The most commonly seen complication is continued severe postoperative pain with failure to reconstitute the longitudinal arch on weight bearing and a residual flatfoot deformity".

Therefore, they do not recommend subtalar arthroereisis in the treatment of painful flexible flatfoot in children.

A study by Koning [127] described the surgical technique involved with implantation of a custom-built cone-shaped implant; the secondary aim was to retrospectively evaluate satisfaction, clinical and radiological results, and complications with a minimal follow-up of five years. Over 10 years, 40 children (80 feet) with a mean age of eight years (range, 4-11 years) underwent subtalar arthroereisis for flexible flatfeet. After temporary sinus tarsi tenderness (12 feet), implant dislocation (two feet) was the most common complication. Questionnaires from 27 participants (54 feet) were analysed and clinical and radiographic results were evaluated for 44 feet. Thirteen children were lost to follow-up. The mean follow-up was 12.6 years (range, 5.9-16.1). Eighty-one percent of the responders reported satisfaction with the results. Clinically, normal alignment was present in 14 feet, and mild deformities remained in 26 feet. The average foot angle measurements were radiographically normal. The authors concluded that subtalar arthroereisis is a simple, minimally invasive operative option with satisfactory subjective and clinical results after mid- to long-term follow-up for children with flexible flatfoot.[128] Several limitations of this study were acknowledged by the authors. In addition to its retrospective design, they were unable to compare the postoperative results to the preoperative situation as subjective (validated questionnaires) and radiological data were unavailable. Secondly, there were mild deformities remaining in 26 feet. However, arbitrary cut-off points were used, meaning that feet with very minor degrees of planus, valgus, or both were also classified as mild deformities.

A retrospective study by Scharer [129] evaluated the radiographic improvement of children who received an MBA subtalar implant for the treatment of painful pediatric flatfoot deformities. In this study, 39 children with a mean age of 12 years (range, 6-16 years) were followed for a range of 6-61 months (mean, 24 months). Statistical evaluation was performed on all radiographic measurements. Radiographic evaluation demonstrated a significant improvement in three of three variables measured on the lateral and anterior-posterior radiographs. Statistically significant improvements were also seen between pre- and postoperative values for each measure, stratified by foot. Additional surgical procedures (gastrocnemius recession, Achilles tendon lengthening, Kidner posterior tibial tendon advancement) were performed in 22 of 68 feet. There were 10 (15%) complications, which consisted of 10 re-operations in 10 feet. Implants were exchanged in nine feet because of implant migration, overcorrection, or under-correction. There was one re-operation (in one foot) for implant removal be-

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cause of persistent sinus tarsi pain. The authors conclude that the MBA implant may be effective for the correction of painful, flexible flatfoot deformity in children in short-term follow-up.[127]

The American College of Foot and Ankle Surgeons has published two practice guidelines for the diagnosis and treatment of adult and pediatric flatfoot.[54, 129] In the pediatric population, proponents of the subtalar arthroereisis argue that it is a minimally invasive technique that does not distort the normal anatomy of the foot. Others have expressed concern about placing a permanent foreign body into a mobile segment of a child's foot. The indication for this procedure remains controversial in the surgical community.[54]

Soft tissue medial column reconstructions

Kidner procedure

The main function of the Kidner procedure (a soft tissue medial column procedure) is to restore the mechanical advantage of the posterior tibial tendon.[6] Other procedures that balance and/or structurally realign the foot may be required, especially procedures involving the rearfoot and/or lateral column.[6] Previous studies have reported good outcomes when using this procedure.[17-19] Blitz [6] suggested that the main purpose of the Kidner procedure is to manage the protuberance of the navicular and/or accessory ossicle, but that it should not be considered as a major reconstructive procedure to restore the medial longitudinal arch when performed in isolation.

The modified Kidner-Cobb procedure utilizes a section of tibialis anterior to reinforce the insertion of the posterior tibial repair.[6] Viegas [130] demonstrated significant changes in X-ray measurements in 17 children (34 feet), over a five-year period, who underwent reconstruction of flexible pediatric pes planus using a medial split tibialis anterior tendon in conjunction with a Kidner and Evans procedures, and tendo-achilles lengthening.

Young tibialis anterior tenosuspension

The Young tibialis anterior tenosuspension, a soft tissue procedure, involves inferior transposition of the tibialis anterior tendon through a slit in the navicular tuberosity, while keeping its native attachment onto the first metatarso-cuneiform joint intact.[6] Cohen-Sobel [131] used a modified Young tenosuspension in conjunction with an Evans calcaneal osteotomy and tendo-achilles lengthening in 10 patients (12 feet) for severe flatfeet. In a retrospective study of 15 feet Dragonetti [132] compared subtalar arthroereisis and tendo-achilles lengthening with or without Young tenosuspension and only found a significant difference between the groups in a reduction of forefoot supination in the group that underwent Young tenosuspension.

Reconstruction involving osteotomies

Medial calcaneal osteotomy

This common procedure is useful when frontal plane deformities of the posterior calcaneal tuberosity exists.[6] The procedure structurally realigns the calcaneus beneath the leg, which restores the biomechanical advantage of the Achilles tendon as a rearfoot inverter.[6] Several techniques have been described and include: 1) obliquely linear osteotomy;[133] 2) calcaneal scarf;[134] and 3) percutaneous technique that involve a Gigli saw.[135]

Evans calcaneal osteotomy

The Evans calcaneal osteotomy has become a primary surgical treatment for transverse plane flatfoot deformities in adolescents because it provides flat foot correction by lengthening the lateral part of the foot (through the calcaneus) yet avoids calcaneal growth plates.[6] Davitt [136] reported good postoperative scores and improved radiographic scores (talonavicular coverage angle and talo-first metatarsal angle in a mean follow-up of 11 months), in nine children who underwent distal calcaneal lengthenings. Mosca [137] performed flat foot reconstructions (or skew foot reconstructions) in 20 patients with an Evans calcaneal osteotomy for severe and symptomatic flat foot. In five patients with skew foot, a Cotton medial cuneiform osteotomy was also performed. Follow-up was from five to 16 years. Satisfactory clinical and radiographic correction was achieved in all but two children.

Double calcaneal osteotomy (medial calcaneal osteotomy and Evans calcaneal osteotomy)

Pomeroy and Manoli [138] reported on combining transverse plane correction with an Evans osteoto-

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my, and frontal plane correction with a medial calcaneal osteotomy, by performing a double calcaneal osteotomy for adolescent and adult flat foot. Catanzariti [139] used this procedure in eight patients with either adolescent flatfoot or adult late stage II posterior tibial tendon dysfunction. Moseir-LaClair [140] performed 28 adult flat foot reconstructions using a double calcaneal osteotomy, combined with flexor tendon transfer and tendo-Achilles lengthening. The mean postoperative ankle-hindfoot American Orthopedic Foot and Ankle Score (AOFAS) (maximum score of 100 indicating no pain) score was 90 with a mean follow-up of five years. Blitz [6] reported that a major advantage of the double calcaneal osteotomy in adolescent patients is that multiple planes of deformity can be corrected with preservation of the growth plates.

Cotton medial cuneiform osteotomy

The Cotton medial cuneiform osteotomy is a procedure known for its use in pediatric and adolescent flexible flat foot, and it is used for medial column collapse.[6] The advantages of this technique (compared with first tarso-metatarsal arthrodesis) include predictable union, preservation of first ray mobility, preservation of the open growth plate, and the ability to easily vary the amount of correction.[6]

Medial column arthrodesis

Medial column arthrodesis procedures are considered when the flexible flatfoot is associated with skeletal maturity or when the growth plates are nearly closed.[6] This procedure is indicated for medial column instability that results in collapse. Dockery [141] advocated medial column fusion to correct instability as an adjunctive procedure in the surgical treatment of symptomatic juvenile flexible flatfoot. In addition, el-Tayeby [142] reported significant improvement in radiographic alignment using a combined medial column fusion (naviculo-cuneiform joint) along with an Evans osteotomy, tendo-Achilles lengthening, and plantar re-routing of the tibialis anterior tendon, in 11 patients (19 feet) with an average age of 10.7 years.

By way of summary, the type of surgical treatment used depends on the underlying pathology and which planes of the foot are affected.[143] Surgery may include one or more procedures, depending on clinical and radiographic evaluation. An algorithmic approach has been reported in the literature.[144] The evidence illustrates several small studies of different surgical treatments finding varying degrees of radiographic and symptomatic improvement. Very few studies reported long-term outcome data. Significantly more prospective studies are required. In the future, studies should be performed to evaluate long-term follow-up in pediatric patients to assess the longevity of correction and subsequent treatment needs.

Discussion

Critical evaluation of the evidence regarding the effect of non-surgical interventions on flexible pediatric flat foot draws no definitive conclusions. This is largely due to the heterogeneity and methodological weaknesses of the studies.

No evidence indicates that orthopedic footwear or foot orthoses immediately improve the radiograph parameters in children with flexible flat feet. All studies investigating the immediate effect of footwear and foot orthoses found an improvement in foot posture. The studies which evaluated the effect of interventions on radiographic parameters over time found no significant difference between the groups. Two studies [28, 112] favor rehabilitative exercises, but the methodological quality was poor in both investigations. Previous studies which found an improvement over time in radiographic parameters of foot posture did not include a comparative control group against the tested intervention. As a result, many studies did not account for normal physiological arch development.

The effect of footwear with foot orthoses has been investigated by only two studies, both of which found a significant decrease in foot abduction.[114, 116] Given that footwear is implicit for all shod gait and the use of all forms of foot orthoses, the lack of discrete investigation of footwear effects is curious.

Whilst the existing results for pain are conflicting, (with the highest quality study finding no difference between groups in the effect of foot orthoses on pain [57]), it is pertinent to note that most presentations of pediatric flatfeet are not overtly symptomatic.[35, 108]

Pediatric flatfoot is a common condition and remains a regular presentation in pediatric health-care

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settings.[32, 145, 146] Discounting rigid or other pathological cases, which constitute the minority of flatfoot presentations, the main issue and long remaining, contention focuses on when to treat these children.

With confidence the clinician can responsibly treat symptomatic, flexible flat feet as this is clearly necessary intervention. The mode of treatment is less straight-forward, but can be fairly assessed against resolution of symptoms in most cases. The most cost-effective options should be used whenever foot orthoses are indicated. Many low-cost, generic foot orthoses can provide good positional support of the child's flatfoot and relief of presenting symptoms.[59] Given the lack of evidence to support the use of customized foot orthoses in asymptomatic children, it is important that this practice desists. Clinicians can be greatly assisted by taking an evidence-based approach to the pediatric flatfoot, as is pragmatically provided by the p-FFP (Figure 2). This reliable framework for assessment and management offers a structured check-list approach to significant clinical findings including: age, pain, gait, footwear, weight, flexibility, arch height, heel position.[105] Global factors which may be apparent or sub-clinical eg neurological, muscular, genetic, collagen, in addition to family history and foot strength, may also be relevant considerations. The normative findings/age which are now available for the FPI-6, may also assist the process of bench-marking foot posture.[63]

Conclusions

Surgical management of pediatric flatfoot has limited and specific indications. There is no evidence which supports the use of surgical correction of the typically asymptomatic and flexible pediatric flatfoot. There is limited evidence for practitioners for the efficacy of non-surgical interventions for children with flexible flat feet. Clinicians need to consider the dearth of good quality evidence in their decision making for the management of pediatric flat foot. Although there is no substantial evidence, many studies suggest that interventions may have a beneficial effect on pediatric flat foot, indicating that further research needs to be conducted.

Future recommendations for research include the use of valid and reliable methods of classifying flat foot and measuring outcomes which appropriately assess the benefit of the intervention being tested. Due consideration of the natural history of flat foot in the younger age group, emphasises the need for control groups and comparisons between the intervention and control groups. Broader participant age range is required to allow for comparisons between age groups and similarly, larger sample sizes with longer follow up periods are required, to enable identification of intervention effect. Comparisons between normal children and those within specific disease groups ie cerebral palsy, Down's syndrome, rheumatoid arthritis, diabetes would also serve to identify relevant deficits and possible treatment benefits.

The current best evidence for managing the typical, painless and flexible pediatric flatfoot is offered in concert by the Cochrane library systematic review of randomised controlled trials, the critical review of non-surgical interventions for pediatric flatfoot, clinical guidelines, the collections of studies emphasising the natural history of the pediatric foot arch development, the influence of overweight/obesity and awareness of the emerging areas of foot strength and rehabilitative exercises.

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