Charles University
Faculty of Physical Education and Sports

Literature Review

Pes planus in children: its implications and the influencing factors on its development

Master's thesis

Prague, September 2013

Submitted by: Farah Droubi

Supervised by: PhD. T. Novakova

Declaration of authorship

I declare that the work presented here is my own, to the best of my knowledge and belief, with use of information gathered from various books, online journals and articles, consultations and seminars. Under no circumstances, has any work been copied, forged or changed and where formulations and ideas are taken from sources, it has been, with every effort, cited as such.

Prague, September 2013 Farah Droubi

Acknowledgment

I wish to take this opportunity in acknowledging the advice and support provided by my supervisor PhDr. Novakova. Her assistance, patience and understanding were all greatly appreciated throughout the course of this thesis. I would also like to take this opportunity to express my deepest gratitude to my fellow classmates for their constant encouragement and their belief in me when I needed it the most. I am also very grateful for the cooperation and motivation I received from my dear colleague and friend, Lousin Moumdjian, not only throughout the course of this thesis but to our entire course of education in Prague.

Lastly but not least, I specially thank my mother, whom I owe my deepest gratitude to as she was, with her unconditional love and support, my constant inspiration in making it this far. I also wish to thank my family, and I could not have made it without the support of Uncle Samir, who made all the difference in me being in this position and I am eternally grateful for that.

Abstract

Title: Pes planus in children: its implications and the influencing factors on its development

Background

Pes planus is one of the most common diagnoses in the pediatric field; flexible flat foot being the most prevalent. This developmental type of flatfoot is a normal finding in young children, seen to resolve spontaneously with growth and development and also remain asymptomatic. Despite this, there is still a large incidence of flat feet in adolescence and many cases of adult flatfeet are frequently presented as residual pediatric flatfeet. The factors that influence the prevalence of flatfeet during a child's development have also the capacity to altering its course and gaining insight on what they are and their influence aids in diagnosing, treating and preventing flat feet.

Purpose

The aim of this literature review was to enhance knowledge on the persistence of the flat feet condition in the pediatric population by determining the development of flat feet in children with an outline of its affect on posture and gait and identifying contributing factors that affect the incidence and progression of the deformity.

Methodology

An electronic database search was conducted to obtain articles from relevant journals (from early 2012 to mid 2013). Only full text English articles were obtained, with a few exceptions. Further information was collected from online textbooks and the reference lists of the studies were checked for further articles.

Results

Many studies found, identified and correlated factors that are significant to flat feet development. However more studies are required on the differences between symptomatic and asymptomatic populations with regard to the factors. There was insufficient evidence on the persistence of flat foot from preadolescence including its prevalence, contributing factors and concepts behind it.

Conclusion

Increasing knowledge of the extrinsic/intrinsic factors influencing flat foot development leads to insight on the likelihood of having flat feet, its cause, and its possible outcomes in the future.

Keywords

Pediatric, flat feet, maturation, medial longitudinal arch, posture and gait

Abstrakt

Název: Pes planus u dětí - důsledky a faktory ovlivňující jeho rozvoj

Pozadí

Plochá noha je jednou z nejčastějších diagnóz v pediatrii; převažuje flexibilní typ ploché nohy. Tento vývojový typ je u malých dětí běžným nálezem, růstem a vývojem spontánně vymizí a zůstává asymptomatický. Nehledě na to je vysoký výskyt u dospívajících a také je často mnoho případů ploché nohy v dospělosti prezentováno jako přetrvávající pozůstatek z dětství. Faktory, které ovlivňují výskyt ploché nohy během vývoje dítěte, mají také kapacitu na změnu jejího průběhu a pomáhají v diagnostice, léčbě a prevenci ploché nohy.

Účel

Cílem této rešeršní práce bylo zlepšit znalosti o přetrvávání podmínek vzniku ploché nohy v dětské populace zjištěním vývoje ploché nohy v dětství s nástinem dopadu na držení těla a chůzi a identifikaci faktorů, které přispívají k výskytu a progresi deformity.

Metodika

Byla prohledána elektronická databáze ke získání článků z vhodných odborných časopisů (od začátku roku 2012 do poloviny roku 2013). Byly vybrány pouze plnotextové články, s několika vyjímkami. Další informace byly shromážděny z on-line učebnic a také byly kontrolovány citace v pracích za účelem získání dalších článků.

Výsledky

Mnohé studie nalezly, prokázaly a korelovaly faktory, které jsou významné pro vývoj ploché nohy. Jsou však potřebné další studie o rozdílech mezi symptomatickou a nesymptomatickou populací vzhledem k těmto faktorům. Nejsou dostatečné důkazy o přetrvávání ploché nohy z dětství včetně jejího výskytu a přispívajících faktorů.

Závěr

Rostoucí znalost vnějších / vnitřních faktorů, které ovlivňují rozvoj ploché nohy, vede k náhledu na pravděpodobnost vzniku ploché nohy, jejích příčin a na možné dopady v budoucnosti.

Klíčová slova

Pediatrické, plochá noha , dospívání, střední podélná klenba, držení těla a chůze

Contents

List of figures

List of tables

List of abbreviations

2D – 2 dimensional

3D – 3 dimensional

AA – arch angle

ADD – adduction

AI – arch index

BMI – body mass index

CA – Clarke's angle

CIA – calcaneal inclination angle

CFR – contact force ratio

CNS – central nervous system

COP – center of pressure

CP – cerebral palsy

CPG – clinical practice guideline

CSI – Chippaux-Smirak index

DF – dorsiflexion/ dorsal flexion

DSIS – dynamic stabilizing innersole system

ER – external rotation

FF – flat foot/feet

FFF – flexible flat foot/feet

FFP – flat foot proforma

FPI – foot posture index

GM – gross motor

IR – internal rotation

LE – lower extremity

LLA – lateral longitudinal arch

LS – lumbo-sacral

MLA – medial longitudinal arch

MT – metatarsal

NSAID – non-steroidal anti-inflammatory drug

OM – outcome measure

ORT – orthopedic

PKK – postural knock knee

PF – plantar flexion

RCT – randomized clinical trial

ROM – range of motion

SI – Staheli index

VAS – visual analog scale

VGRF – vertical ground reaction forces

WB – weight-bearing

WHO – World Health Organization

1 Introduction

1.1 Introduction

Pes planus (otherwise known as flat feet) is one of the most common orthopedic diagnosis in the pediatric field. It is the presence of a fallen or absent medial longitudinal arch of the foot. The majorities of flatfooted children have a physiological and flexible form of flat feet and it is for this reason that this population is the main targeted one in this review. This developmental type of flatfoot is a normal finding in young children, seen to resolve spontaneously with growth and development and also remain asymptomatic, as it is a part of the natural pattern of development and is a reflection of the combination of CNS maturation, musculoskeletal maturation and growth. Despite that, it still remains as one of the highest reasons for parents to visit their physicians' with their children to seek intervention with worry about their maturation.

There are many factors that influence the prevalence of flatfeet during a child's developmental period and have the capacity to altering its course. These factors consist of intrinsic features such as genetics and extrinsic such as types of footwear. None of these factors are independent of each other as they all could affect one another. There is no lack in studies of factors correlating with flatfeet and of issues that affect its physiological development. The main motivation of this review is to increase knowledge of those factors, however with an insight to its possible connection on the development and progression of the deformity into adulthood.

Even though it has been clearly proven that the natural developmental pattern of flexible flatfeet comes decreasing with age, many cases of adult flatfeet are frequently presented as residual pediatric flatfeet. A purpose of seeking the answer as to why this relation exists in large numbers is one of the goals of this literature review. Since these influential factors are constantly impacting the foot posture, even after the developmental period has ceased, gaining insight into what they are and how large their impact is on the incidence can provide a good basis for investigations on which factors are most critical, which could be modified to play a major role in preventing the progression of flatfoot and which could aid in diagnosis and management of flatfeet in children.

To learn the extent of how much flatfeet affects the posture, gait and development of children is another aim of this review and information on these relations, their inter-related parts and their implications will be provided and discussed as it will lead to a better understanding of its clinical important in the pediatric population.

The intention of this review is to gather and provide information on; [1]the development and maturation of the foot in children and aspects from that which are related to the presence of flat feet, [2]the most important biomechanical aspects of the medial longitudinal arch and the implications of the foot on posture and walking, [3]the prevalence, classification, method of diagnoses and treatment of pediatric flat feet to enhance knowledge on the condition and locate gaps, and [4]provide a review of the various factors influencing the development in the available literature. Following the evaluation of the literature of all the aspects of the pediatric condition is the discussion, where the main results will be presented and interpreted with the key highlights and finally a summary of the findings will be provided at the end of the review in hopes to conclude some efforts that could be made in management and prevention of acquired flatfoot.

Note that although the topic of the diagnosis and treatment of flat foot is beyond the true scope of this paper, some issues of it are necessary for its connection to the other areas of the review and will be included to provide a clearer understanding.

1.2 Methodology

Design – The design of the dissertation is non-experimental and will be a 'review of literature'.

Search

The targeted population of the search was the pediatric population (no specific age group), with a few exceptions, and populations with normal developing or with flexible flat foot, also with a few exceptions. Journal articles and scientific literature from electronic databases, through *'PubMed'*, was the main source of literature with a language restriction to English only. No date restriction was placed, unless more valuable newer studies provided the same information, then the older ones were discarded. Also some information, of anatomical or biomechanical origin, was attained from online books.

A total of 122 sources were cited in the literature review of all study types. 20-35 articles provided information on flatfoot related to gait and posture dynamics, 30-35 provided information on factors influencing flatfeet, 30-35 articles were used regarding the diagnosis and treatment of flatfeet and 15 and more articles that describe the development in children.

The collection of articles was in the period from 2012 – August 2013.

Search strategy – search terms and phrases used included 'pes planus in children', 'flat foot in children', 'pediatric flatfoot', 'factors of flatfoot', 'correlating factors in flatfoot', 'effect of flat foot on..' and 'influence of flatfoot on..', 'developmental flat foot', 'arch maturation', amongst similar others.

Limitations – limitation may be from the evidence available that is appropriate or related to the purpose of the review. Also, many suitable articles found were not accessible nor in English.

Articles/Results

Inclusion criteria – Articles that include subjects with bilateral flatfoot in children. For evidence-based clinical trials, clinical practice guidelines, and systematic reviews: articles that are no older than 15 years. Related material with theories about the flatfoot condition. Articles that were in English and with full text availability. Articles that relate to the topics of interest, for the pediatric flat foot population. Articles of all study types were included to allow all the concepts bordering the topic to be evaluated.

Exclusion criteria - Most articles with only abstracts or limited access were excluded, with very few exceptions of 2-4 articles only. Also articles about rigid flatfeet or flatfeet caused by pathological disorders were excluded along with articles on treatment of them. Majority of articles that provided information regarding adult flatfeet only, with a few exceptions, were excluded. Case study reports were mostly excluded with the exception of 1-2.

Topics of interest – As mentioned above relied mostly on factors influencing the flatfoot in developing children and topics that revolved around the impact of flatfeet on posture and gait and its implications. Also articles about the diagnosis, treatment, classification of flat feet, its development and prevalence.

Evaluating the evidence

With the above search strategy and target, articles were firstly assessed by their titles and abstracts and if found relevant, were included. Full text articles were then accessed when available and excluded when not (if the abstracts did not provide sufficient or significant information). Materials and studies were classified on their quality according to their methods of analysis and type of design (highest being randomized clinical trials, systematic reviews and clinical practice guidelines and lowest being case reports) and all study types were reviewed but more attention on results was focused on the high quality articles. Reference lists from the articles were also evaluated to search for further relevant articles. The information that the article provided was in more concern than the specific methodology of the studies.

2 Literature review

The results of my methodology have been arranged in an order found most suitable regarding the content of the literature collected. The framework of my literature review will include firstly descriptions of childhood physiological development with an emphasis on the lower extremities and include areas of anatomy of the foot and ankle complex and the normal/physiological foot arch development, which all create a theme of a more 'static' part of the thesis.

The framework then shifts to more 'dynamic' aspects and involves a biomechanical overview with an emphasis on the medial longitudinal arch and then the foot in dynamic functions within the content of gait (primarily in children). An important chapter to close the second part of the review is regarding the implications of flat feet in posture and gait along with the effect of its posture on the biomechanics of the lower extremities and proximal areas.

The third and final part is on the generalized subject of flat foot in children, its etiology, characteristics and prevalence. Being that there are several different *types* of flat feet that exist, those are highlighted also, along with their methods of diagnosis and treatment with up to date literature. The latter will then be an interpretation and review of the literature collected related to the factors that influence flat foot development by increasing or decreasing its incidence and likelihood. At the end of each chapter a short conclusion or summary will be provided regarding the most significant findings and important areas throughout this review.

Finally, a short discussion of the results and a conclusion summarizes the main and most significant findings.

2.1 Child Growth and Development

Human development is a continuous synchronized process of growth and development (1). In especially pediatric care, there's a great importance to know the phases of development a human undergoes. Knowledge of these phases allows early detection of any delays that may require intervention (2). Early therapy has proven to promote physiological movement patterns before the process becomes more adapted and difficult (2).

Development is defined as a maturational change; that goes from a lower stage of complexity to a higher one. Growth, being also maturational, is the process of a change in size and volume (usually an increase rather than a decrease) (1). Both of these processes are affected by many factors such as hormones, genetics and force, and the amount and timing of these factors are crucial to the formation of body parts (1). The importance of this influence will be discussed later in relation to the many associated factors that can affect the development of the foot complex.

A normally developing child reaches motor *milestones* at certain ages. These milestones are necessary to know if there's an aim to differentiate an abnormal development from a normal one. A milestone disturbance may indicate a wide spectrum of problems (2). The sequence of gross motor development progresses in a cephalo-caudal direction whereas on the other hand, fine motor development progresses in a proximo-distal direction (3). In this view, the foot is always the most distal point of both these progressions where achieving bipedal stance and locomotion is towards the end stage of the main motor milestones.

Blasco (4), highlights 5 main areas in the assessment of motor development, and these include: [1)] the motor milestones, [2)] a neurological examination, [3)] primitive reflexes and postural reaction patterns (which should gradually be absent to allow more voluntary movements) (3), [4)] the change in functional and neurological status, in relation to time, and [5] other evidence on supporting pathology that exists.

Table 1 in Appendix II outlines the gross developmental findings (2). Infants are thought to acquire sitting with support at 6 months, crawling around 9 months, walking with support at 1 year and without support at 15 months (5). For each milestone, there's a range of ages for the motor ability to be met, especially for the age of onset of walking, where it can be as early as 11 months to as late as 15 months where both are considered as normal (2). This milestone has a significant importance to the development of the foot arches. The longitudinal arch starts developing as soon as the foot becomes loaded in bipedal stance and gait, however the speed of this development varies a lot (6, 7).

2.1.1 Anatomy and Development of the Foot-Ankle Complex

For the relevance to this review and ease of following, only anatomy that is relevant to the medial longitudinal arch (MLA) and its changes will be reviewed.

The foot has a quite complicated structure compared to other regions of the body (*see Appendix I - Figure 1)*. It is comprised of 26 bones and over 100 of joints, ligaments and muscles working together (8). Their complex structure allows for their ability to mold onto different types of terrain and to withstand the great forces put upon them, despite their size. Depending on the situation, the foot can act rigid (for support), or flexible (like as in walking on sand) (9).

The foot has 2 surfaces; the dorsal and plantar surfaces. It's made up of 3 major functional parts; the forefoot (which is made up of the phalanges and metatarsals), the midfoot (which refers to 5 bones that fit together in 2 rows), and the hindfoot (which is made up of 2 large bones, the calcaneus and the talus) (8). In *Appendix I - Figure 2*, the foot axes and motions are shown.

The talus is the bone that connects the foot to the lower leg via its articulation to the distal tibia and fibula (talocrural joint), therefore it is referred to as the ankle joint. The ankle transfers load from the lower extremity (LE) to the foot (9) and carries the load.

The foot must bear combined forces that reach more than 50% of the individual's body weight. In a *normal* weight distribution of the foot, the body's weight is in fact distributed over 3 points mainly. These points form a triangle and they are the heel, and under the heads of the I. and V. metatarsals (MT's) (8, 10). There are 2 arches between these points; the medial longitudinal arch and the lateral longitudinal arch and they're at right angles to the third transverse arch. The arches are maintained by; [1]the ligaments (and the tendons of some muscles), [2]the shape of the bones, and [3]the muscle activity from supporting extrinsic and intrinsic muscles (11).

(i) Longitudinal arches:

A: Medial longitudinal arch (MLA) – this arch is most clinically significant out of the rest as its height is the main characteristic that presents the variability of FF (12, 13). It forms the medial border of the foot and connects from the calcaneus through to the talus, navicular, the 3 cuneiforms and goes anteriorly to the first 3 MT's. The arch's key point, which is its most upper part, is the talus as it receives the weight of the body (10).

B: **Lateral longitudinal arch** (LLA) – this arch is slightly elevated and only allows a limited movement (14). It's composed of the calcaneus, cuboid bone and the IV-V metatarsals. It is supported by the long plantar and the calcaneocuboid ligaments, extensor tendons and the intrinsic muscles of the small toe (11, 10). The LLA's active support comes from the muscle actions peroneus longus (10).

(ii) Transverse arches: are made up of series of arches between the posterior part of the metatarsus and the anterior part of the tarsus and have a shape of a half dome.
The best advantage of the transverse arches can be seen in the region of the cuneiform bones (10). The transverse arches are strengthened by the interosseous, plantar and dorsal ligaments, intrinsic muscles that support the longitudinal arch also and the tendon of the peroneus longus. (11)

Because of its many compartments, the MLA is very elastic and strong. It is also higher and firmer than the LLA (14). The weakest part of the arch is the joint between the talus and navicular, which is supported by a strong spring ligament called *calcaneonavicular ligament* (11). This ligament provides medial support of the MLA and also prevents medial/plantar displacement of the talar head (9, 10). The main passive support structures of the foot can be seen in *Appendix I – Figure 4* (10). The active support structures of the arch, being the muscles of the foot and lower limb will be mentioned in the later chapter of this review.

A normally aligned foot is defined when the height of the MLA is in a normal range with the foot in neutral position. Based on the structure of the MLA, 3 types of foot have been suggested – [1] normally aligned foot, [2] a low arched or pronated foot (pes planus), or [3] a high-arched or supinated foot (pes cavus) (13).

A pronated foot is defined when the calcaneus is in everted position (valgus position of the heel) and the arch is low or flat, and a supinated foot is defined as the foot with an inverted calcaneus and a high arch (*see Appendix I – Figure 5*) (10). A supinated foot is more rigid whilst a pronated foot is more flexible allowing more load absorption via the muscles of the feet. The midfoot is usually the area of highest plantar pressure in pronated feet (6, 7, 15, 16, 17).

The first manifestation of foot development can already be seen in the 4th week of gestation where eventually the foot turns to extreme inversion position until about week 16 (6). A torsion of the talus and calcaneus encourages the feet to be everted and gradually turns the feet to a more neutral position by 28 weeks (1). There’s a common forefoot varus of upto 5^0 until the age of 2 years (this decreases with rotational changes of the talus which is moreover caused by rotational changes in the tibia). The calcaneus is also in varus position of 22^0 in relation to the tibia, and this continues to a valgus rotation until it reaches a relative perpendicular position by maturity. This eventually counterbalances the normal external rotation (ER) of the tibia (1, 18).

The foot of a newborn is quite elastic and flexible. There’s a high range of motion (ROM) of dorsiflexion (DF) and forefoot adduction (ADD) (more than plantarflexion and forefoot abduction). The MT’s are also in adduction, but this decreases with age. The arches are also present but less visible as they are covered by thick fat pads at the plantar surface of the feet (1). The fat pads protect the feet from overloading by distributing the pressure across the surface of the foot more evenly (6). This is an important protection as there’s a lack of normal muscle strength and ligament tightness at the onset of walking to maintain the arch. Infants and toddlers, therefore, present with physiological flat feet before and after starting to walk (19). The term pes planovalgus is given for this because at initial stance of a toddler, the weight falls medially to the hallux and causes pronation of the foot, flattening it, placing the heel in a valgus position (1, 19). This pronation gradually improves with the development of the arch. From 2 years of age, the out-toeing is minimal and the arch can more or less be maintained (1).

In the prenatal development, the lower limb undergoes a lot of rotational and torsional changes that are a part of the developmental pattern (1). These changes are most of the time physiological, however a correct diagnosis is important to exclude a pathology if these changes persist for longer than normal (19). The rotations that exist from birth appear to be from the intrauterine molding, as in the utero, the hips are in flexion with ER and the feet are in IR position. This gives the ER position of the hip and IR of the tibia pattern at birth (20).

As there’s an indirect relationship between the position of the hip and the position of the knee, knowledge of what positional variations the proximal joints go through, is necessary to connect their influence on the foot’s position. In the context of axial/angular deformities, an infant or child can present with either genu valga (knock-knees) or genu vara (bow-legs). Until up to 3 years, because of rotational changes at the hip and knee joints (1), where the hip tries to equalize by externally rotating, children present with physiological genu vara (19, 20). Therefore children often look bowlegged at the time they begin to walk (21). Reported norms for this ER range from 25-65^0 (in both females and males) (20). However, after the age of 3-4 years, they frequently develop genu valga, which spontaneously corrects itself by the age of 7 years (19). This change may be a cause of the widening of the pelvis with growth of the child (21). The correction of genu valgum and development of the medial longitudinal arch usually occur around the same period of time, from 5-6 years of age (15). A sign of a possible underlying disorder can be seen in persistence of genu valgum after the age of 7 but even a decrease of genu valgum before 6-7 years of age can be also recognized as a pathology (19).

The tibial shaft has an IR of 5^0 at birth which increases to about 23-25^0 of ER by early childhood, therefore a persistent IR can be due to a functional failure (1, 22). The IR rotation of tibia has a direct effect on the position of the feet so this gradual increase in ER with maturity causes a decrease in valgosity of the hindfoot which aids in elevating the medial longitudinal arch (MLA) (20). A normal developmental pattern of rotational deformities in children is; [1]out-toeing position of the feet in infants, which progresses to [2]in-toeing position in toddlers (from the internal tibial torsion and/or metatarsus adductus and from the change of the hip position from ER to IR), which then progresses to an [3]IR of the femur in young children (21, 23). When the IR is present more at the hip joint, femoral anteversion is increased, and it becomes the main cause of in-toeing gait in early childhood (19). This femoral anteversion peaks at the age of 4-6 years but then gradually disappears (21, 20). With an increased hip IR, the most common compensation and adaptation in a child is ER of the tibia and pronation of the feet (1). This point marks the importance of knowledge of the whole spectrum of physiological changes in the lower limbs of children when it comes to diagnosing disorders in the pediatric care.

All these developmental changes of the lower limb show a large variation within small time frames. There is a large inter-individual variability between infant’s feet because of this, and it makes it hard to distinguish normal from abnormal (24). However, it’s essential to keep in mind that many of these changes are physiological and don’t need special care or treatment which are many times being given unnecessarily. A high number of special shoes and foot orthotics are being prescribed to children with rotational deformities, even though these deformities are not caused by foot problems and just merely by normal developmental changes occurring in the joint kinematics (19). Also, a child younger than the age of 3, go through rapid growth changes that result in many findings that may seem abnormal, especially when comparing them to adult-like patterns, therefore characteristics of the development are more significant as the child grows (21). The child below the age of 3 presenting with flat feet is almost meaningless, unless of a rigid type, because of the presence of the fat pad, lack of ligamental tightness, muscle strength and walking experience. However as the child grows, the presence of flat feet can be a sign of a delay in development or a deformity and becomes more of a concern that may need further evaluation (14).

2.1.2 Growth of the Foot

The length of the lower limbs can commonly be slightly asymmetric. A leg-length discrepancy in a growing child of 2 cm is the acceptable limit (19).

The length of the foot at birth is an average of 7-10cm. Half of the adult foot length is reached by first year after birth (6). This contrasts from the fact that the femur and tibia don't reach their mature length until few years after that, therefore the large foot size is vital as to providing a good base for support which can also compensate for lack of balance and control (9). The average width of the foot is half of its length at birth and a third of its length in an adult (1).

From the age of 5 until puberty, the length of the foot increases about 0.9cm/year (7, 9). In several studies on the development of the foot morphology or prevalence of FF in children, (6, 12, 25, 26, 27) it's been shown that girls' development of the feet occurs earlier than in boys and that boys' feet grow for a longer period of time. By age 10, girls' would have reached 90% of their whole foot length, whilst boys would've reached just about 82% (1).

Another important aspect on growth of the foot is the ossification of the bones. Final ossification of the ankle-foot complex is prolonged, leaving it more time for growth or deformity. The growth centers don't completely fuse until late puberty which means that a relative amount of correction is always possible (1). The partially ossified centers are connected by soft tissue (16). Ossification of the cuneiforms and navicular occur from 4 months to upto 5 years of age. The head of the talus develops during the first 2 years, and the sinus tarsi develops at 4 years. From 4 years of age, the secondary ossification centers begin to develop until complete fusion in adolescence (1).

There is a possible strong relation between the incomplete ossification and the presence of flat feet in children. Although there's a physiological gradual development of the ossification of the bony structures in the foot, development of the arch with a resorption of the fat pads (10) and central nervous system (CNS) maturity, all interconnected, with the normal biological range of loading, there's at the same time a high risk for the feet of children to have a more permanent deformity. In the case of abnormal loading or alteration of the amount of force (from activity, weight of the child and so on), duration and direction of the force may negatively affect the growth. An example of this can be seen by the creep phenomenon caused by a high constant load over ligaments that can cause them to overstretch (1, 28).

As previously stated, many factors can influence the formation of any body part during growth and development. Mechanical forces, specifically, have a large influence on the musculoskeletal system. Since the foot is the most distal point of the (lower) kinetic chain, it makes it very susceptible to changes at all stages of development especially when being loaded in the erect position; it is most vulnerable, as it carries the entire body weight (1). It is logical to postulate that excess mass or excess load can cause an effect on the foot structure and peak pressures in the foot, whether or not the feet are flat or if it is in an adult or a child but it is important to highlight that in children, there's still an incomplete fusion of the small bones of the feet leaving it more vulnerable to deformity and/or injury which can affect its growth and development. This brings about a conclusion of some reports that have suggested that premature weight-bearing predisposes children to flexible pes planovalgus (1).

These connections can emphasize the importance of the foot posture and how it can be affected by positions of different body parts and vice versa. To summarize, postnatal deformities may be caused by abnormal load. Also, congenital deformities or positions of proximal joints can change the loading patterns on the feet, consequently resulting in compensatory positions. The most common compensation for these deformities is abnormal pronation.

2.1.3 Maturation of the Arch

It is stated that FF is a physiological phenomenon that is corrected with age without the necessary need of treatments, as it is part of the CNS and musculoskeletal maturation (29). The longitudinal arches are formed as an adaptation to resist load (16). The MLA is therefore a vital part of foot biomechanics and any change in its height or volume (a significant increase or decrease) from the 'norm' can cause changes in muscle balance, gait, and alignment of joints (17). Unlike the physiological aspect of a low arch, a high arch is not so common in children and normally represents pathology (usually of a neuromuscular disease) and requires further attention (17).

Many different authors have stated different time periods in where the arch maturation occurs in the developing child. The primary developmental stage is in the preschool period (25). It's also been postulated that the maturation is ongoing from the ages 3-10 years and more, with a peak of a critical stage of development before 6 years (30, 31). Besides the differences present on the period of arch maturation, there is one attribute which seems to be present in the majority of the studies and that is the age – the youngest groups of any study always have the highest number of FF present (no matter what the age groups measured are) and that the prevalence of FF decreases with increasing age (12, 24, 25, 26, 27, 29, 30, 31, 32, 33, 34, 35, 36). The youngest groups also always have a more rapid development (that starts when the milestone of bipedal stance and gait is reached), where a lot of changes are seen, whereas after 3 years of age until puberty, there is a slower maturation.

The studies that investigate development of the foot in childhood always begin with the time of onset of walking because this is the time where the development of the arch is said to begin. The studies for the changes that occur in toddlers between the ages 1-3 years are also normally longitudinal designs to allow better data collection on development and growth (7).

A study that calculated arch volume indexes in children, used a ratio of the difference in volume of the foot between sitting (non-WB position that represents the bony structure of the foot) and one leg standing (full WB that represents the soft tissues and the bony structures) to the volume when in sitting (37). The results showed that the volume index increases gradually with age, also concluding that the arch becomes more and more rigid with age. There were significant differences in ages 3-4 years in the arch volumes, showing the development at its peak rate during the first 2 years of walking. There weren't any significant differences in ages 4-5 years, which is in accordance with another study that showed the development of the foot arch function using Contact Force Ratio's (15). The results can be similar at those ages because of a possible temporary paused development, as it is the age where woven bone that's formed in the fetal period (which is more flexible) is converting to lamellar bone which hardens at 4 years of age (37). However in another research, significant differences *are* found between 4-5 years of age in the MLA but this may be due to different evaluation methods used in the studies (17).

A study examining the changes of foot function in the first 5 months after the onset of walking recruited 10 toddlers at 1, 2, 3, 4, 6, 8, 10, 12, 16 and 20 weeks after their onset of independent walking (16). This period of development was chosen, to be able to detect the first and rapid changes that occur and in this way, aid results of other studies. Variability is very large in young toddlers. In a similar investigation (38), done on children in the first 2 months of independent walking, 3 different foot contact patterns were seen and described after analyses of pressure patterns. The contacts were; [1]initial forefoot contact (toe walking), [2]flat foot contact, and [3]initial heel contact (heel strike). Both studies used pedobarographic data and both also made a comparison to stereotypic pressure distribution patterns of adult walking. The results were also in agreement, and showed that at the beginning (first 2 weeks of independent walking), the majority of foot strikes consisted of initial forefoot and flat foot contacts. After 2 weeks, the toe walking was rare in comparison with the rest and with increasing experience; incidence of a more mature initial heel contact was also increasing (38). The toddlers however tried to keep their FF contact for as long as possible and this suggests that it's mostly to keep their balance and that the gait is still immature after 5 months of independent walking with no consistent patterns evolving. Even though the majority of the toddlers recruited for the studies showed similar results, it's hard to draw general conclusions because the sizes of the samples were very low (consisted of 7-10 children in each study from one population).

In contrast to the results of the previous studies, a longitudinal study on the first year of independent walking showed more developmental features (7). 42 children were recruited (from a German population) at the average age of 14.8 months (the average age for onset of walking is at 13.5 months) and data was collected every 3 months for 1 year. Parameters such as contact area, peak pressures, and maximum force were collected using pressure platforms. The foot was also subdivided into 5 functional regions (hindfoot, midfoot, forefoot, big toe and lateral toes). Results showed that the foot regions didn't present the same changes at the same time and that the midfoot region was developing in the opposite way; there was an increase in all parameters in all the regions except in midfoot and lateral toes where there was a decrease in the parameters. This may reflect on the arch development changing the loading and pressure patterns of the foot along with absorption of the medial fat pad or remodeling of the bones in the hindfoot, which is caused by higher muscle activity and loading changes upon the foot (7). The gait was also seen to be more dynamic by 1 year of independent walking from an increase of the total max. force (from 95% to 115%), and this decreased by 5% under the midfoot. The two main developmental features observed during this study was that, [1)]there was an increase of indentation in the medial side of the foot, and [2)]an improvement of gait cycle with more physiological roll-over. The comparison of the results' of the studies of toddlers between 1-5 months after the onset of walking and the longitudinal study that carried on to upto 1 year, showed a lot of differences for the span of only 5 extra months of investigation as more developmental findings were observed. This supports the evidence that there is a rapid development between 3 months until 1 year after walking, and a slower phase up to 8 years (16).

The improvement of the gait cycle and a more dynamic roll-over process is seen when there is an increased loading of the foot regions, except the midfoot. This conclusion was also the same of another German longitudinal study of 90 children, recruited at the mean age of 15 months (6). The average age in the last appointments was 63 months (around 5 years old). The results here also showed a decrease in the midfoot parameters – the midfoot contact area decreased about 34% from the first to the last appointment and the largest decrease was in the first years (also agreeing with the rapid development present in younger ages). The midfoot peak pressure also decreased by approx. 9% per year, reflecting the foot morphology changes. The modification of the fat pad and development of initial heel contact are reasons for these peak pressure changes as during the development, the fat pad shifts towards the heel and forefoot as it resolves, decreasing the contact area under the midfoot region consequently (6, 7).

One other German longitudinal investigation of the development of FF in healthy children showed interesting results (24). This investigation was carried over 9 years. It consisted of 36 children with an average age of 14.6 months from the initial appointment. There were 17 measurements of dynamic parameters taken in total. The most significant results showed that in the first 3 months, peak pressures were highest under the hallux and with an increasing age, the midfoot contact area and peak pressures decreased (from 30% to 18%). The hindfoot peak pressures were increasing with age but towards the end it was also high in the forefoot. The midfoot parameters, likewise in the previously mentioned studies, all gradually decreased with age, however there was a large range of the width of the midfoot and arch index showing a great deal of inter-individual differences. All these different shifts of peak pressures over the different foot regions indicate the changes of the fat pad, increase of dynamic gait and foot morphology. However, still in comparison to adults, even after 9 years the development is still incomplete but the maximum force and contact area values barely change after 4.5 years. In this study and the previous German study (7), the age at walking onset didn't affect the development of the arch, especially as soon as the child reached the upright position.

An important finding between the previous studies mentioned was the load transfer shift that was often seen in this period, from the midfoot to the forefoot. This forward load shift may be due to the large instability present, because it is also seen in diseases such as Parkinson's or in elderly. Higher contact area on the forefoot allows higher muscle activity and this can compensate for the stiffer regions of the foot. From that it can be concluded that flat foot and forefoot contact at this age is more of a strategy than immaturity (16, 24, 38). In the already mentioned German study of 90 children, this forward shift was seen occurring up to 1 year after the onset of walking and after that, a load shift to the heel was present approximately after 18 months of walking (children who are approx. 33 months old at that time) (6).

Because of the rapid foot growth from the ages of 1-5 years of age (6), and the resorption of the fat pad that occurs approximately after the age of 3 – the MLA becomes more visible and easier to evaluate on the course of its development, many more studies have followed the development of the arch and foot from ages 3 and above. The results of most investigations are more or less very similar to concluding that the most critical age of development is before 6 years of age as the age groups between 4-5 and 5-6 normally show the highest changes (17, 29, 31). Statistics showed that the 3 year olds have about 5 more times the risk of having FF than 6 year olds which high lights again that the critical age of development being before 6 years of age (31).

There is an increase of external factors playing a role on the development of feet after the age of 3, as the children begin their pre-school period and engaging in more activities with the surrounding environment and for that the majority of the studies always evaluate the possible influence of these factors on the foot development. Since the foot and MLA continue to develop linearly with increasing age, many studies try to evaluate these changes over higher age groups to identify when the arch development starts and when it approximately ends (17).

In a study aimed to characterize and objectify the MLA in Brazilian school kids aged 3-10, it was seen that highest changes in foot formation were seen between ages 4 and 5, but yet also in the age groups 7-8 and 9, however more subtly. Therefore, arch maturation continues past 6 years but at a slower velocity and doesn't stop at 10 years (17). This contradicts some authors' statements that the arch maturation/development occurs up to the first decade of life.

In a more long-term view, a cross sectional study in China aimed their investigation between ages 4 and 18 years (15). The study included dynamic footprints of 2715 Chinese children. The measure used in this study was a new parameter, the contact force ratio (CFR) which is the ratio of midfoot loading to the total loading of the contacted foot (with toes ignored), therefore the higher the value, the lower the arch (15). This ratio gives more information about the arch function rather than its appearance as with some previous studies that evaluated prevalence from static measures only. Merged CFR values of girls and boys were similar in the younger ages (high values), and then decreased 6-10 years of age and plateaued. This pattern of the development is similar to the one seen from the results of the previous Brazilian study. However, from the CFR results, there was an increase in the values again after 12 years of age until 16 years of age before it plateaued again which showed an increase of fallen arches in this age period. This shows a continual change in adulthood which is important to take note of; even after the foot-arch development has matured it is never fully stable and still vulnerable to flat-footedness in adolescence. However, it must be also kept in mind that the study described used a Chinese population only, whom are generally expected to have the appearance of FF more commonly than some other populations because of the general laxity genetically present in the majority of their population (Cheng et al 1991) (15). In agreement though, more studies showed similar findings and changes exceeding 10 years of age, in different populations i.e. the Mediterranean populations (27) and a European one (12).

Therefore a general conclusion can be drawn that truly there is a critical age for the arch maturation before 6 years of age, but there's an ongoing development of foot structures over a wide range of ages and ongoing influence from external and internal factors on the foot (27). So it should be no surprise that changes are still being seen after 6 years of age and that ongoing influence from certain external factors may affect the resolution of physiological flat feet and allow the deformity to continue into adulthood. It is important to note that the arch maturation itself, doesn't depend only on the maturity of the musculoskeletal system, but appears to be due to the interaction of many systems that affect the foot complex and allow it to maintain the arch through some compensatory mechanisms. In an experiment done in Poland on posture control development, children aged 2-7 years old were tested for their COP variability in quiet standing (39). These results, along with the measure of COP repeatability, reflected their postural control development. The repeatability began to increase at age 5, and at 7 it reached its peak, in both feet. It was also noted that there were higher repeatability results in one foot over the other which suggested a leg dominance being established, by 6 years of age (39). This can suggest an indirect effect on arch maturation; as the CNS improves and matures with age, it results in a better muscle and balance control, which in turn allows for better postural control in standing (as there is a higher control over the lower extremities) and better positioning of the foot complex which allows it to maintain and develop the arches under physiological conditions (27). With also the ongoing growth and ossification of the bony structures of the foot, and the gradual ER of the tibia from its IR position, all these systems play a part in better stabilization of the arch and elevating it during weight-bearing (WB) (27). If the vice versa would occur, as in having a disorder than delays CNS maturity or affects the rate of growth or muscle control, a delay in the arch maturation is likely to occur.

2.2 The Foot in Posture and Gait

2.2.1 Arch Biomechanical Overview

The lower limbs require normal alignment and stability to function optimally, specifically the foot and ankle as they are the terminal joints of the limb, connecting it to the ground and carrying the body weight (40). The three major and most important biomechanical functions in bipedal gait that are brought by the foot are [1] accommodation of irregularities of the ground surface and maintaining balance, [2] shock absorption and weight support, [3] generating forward propulsion, and [4] proprioception (large amount of proprioceptors in the sole of the foot) (41). The bones of the feet are mainly responsible for the flexibility of the foot function but on the other hand, the arches support the weight of the human body. The arches of the feet are essential to all of the above functions in gait (14).

The key point of the arch, as its most upper part is the talus bone. It connects the foot to the lower leg via its articulation to the distal tibia and fibula (talocrural joint) and has a precise position as it has no muscular attachments, therefore its stability depends on the ligaments surrounding it and the extrinsic and intrinsic muscles (8, 40). The talocalcaneo-navicular joint, comparable to the hip joint, is a ball-and-socket joint (40). The head of the talus lies against a concave surface where the navicular facet is anterior to it, the anterior part of the calcaneum is in the middle and the sustentaculum tali supporting it inferiorly and posteriorly, with ligaments bounding them together laterally and below (40). Distally from this socket, lie the medial and lateral columns of the foot (the medial being the 3 cuneiforms, first 3 MT's and the toes and lateral being the calcaneum, cuboid and 2 lateral MT's) (40). When the division of load between the two columns is imbalanced because of a dysfunction at the subtalar joint, a deformity is caused as it occurs in FF (40). Therefore, it is important for the subtalar joint to be in neutral position. The subtalar joint neutral position was defined before as the position where the longitudinal midlines of the leg and heel are parallel however Root et al. defined this position as neither in pronation nor supination, and developed a technique of measuring it to support his theory (42). According to his theory, the calcaneum inverts with supination twice as much as it everts with pronation, therefore by calculating the total ROM at the ankle and dividing it into 3, the subtalar neutral position is defined as the end of the first sector moving from eversion to inversion (42).

As the largest arch of the foot, the MLA is the most essential for proper biomechanics of the foot (17). In a model that describes the MLA, the 'Truss model' (see *Appendix I – Figure 3*), it is presented as an arch that is triangular with 2 struts connected by a tie rod as the base (9). The tie rod represents that plantar fascia. The struts are under compressive forces whilst the plantar fascia is under tension. The plantar fascia is the most important passive structure of the arch as it provides it with the highest support. It's responsible for a mechanism called the 'windlass effect' because of its connection to the calcaneus and the MT plantar plates – with DF of the toes, a traction is placed on the plantar fascia causing an elevation of the arch (9).

The arch is moreover supported by its active components, the extrinsic and extrinsic muscles. In dynamic conditions of weight-bearing (WB), the muscles are essential to maintain the MLA. Muscles that are more directly related to the stability of the MLA are; the tibialis posterior and tibialis anterior, the flexor hallucis longus and flexor digitorum longus which give support medially (10). An EMG study on these muscle groups has shown that a decreased activation of these extensor muscles are in fact related to the severity of FF of the children included in the study, emphasizing their importance of their function towards the MLA (43). In another experiment, the effect of tibialis posterior on the arch was investigated (44). The study used 14 cadaver legs to see the influence of a simulated cyclic axial loading on the arch, and compared the situation with and without the tibialis posterior tendon support. It showed that the support of the muscle was essential to maintain the arch as the passive structures alone were inadequate; after 1000 cycles, the navicular height continued to decrease in the passive structure group only. However, around 7000 cycles, showed a critical point for both structures in this study, therefore it can suggest that WB in long periods of time could be a risk factor to dysfunction of the muscle or arch collapse, however the specimens used were of old age (44). Interestingly, the abductor hallucis muscle has also been proven to be an important arch elevator. A study that simulated a contraction of this muscle on cadaver specimens showed that the contraction caused flexion and supination of the 1st MT, inversion of the calcaneus and ER of the tibia which all are consistent with elevation of the MLA (45). In *Appendix II – Table 7,* movements of the foot and ankle and the muscles that initiate the movements are summarized. It's important to note which muscles are involved in which movements, especially when understanding the dynamic biomechanics of the foot and ankle (8, 10, 46).

2.2.2 Gait Biomechanical Overview

It can be generalized that even a small deviation in the structure of the lower extremities may lead to a deviation and change in the gait (structure affecting the dynamic biomechanics) on the basis of many researches. Due to the wide-range of the gait cycle and its phases, for the relevance of this review, only the foot-and-ankle complex's role will be discussed in this section of the review.

The gait cycle consists of 2 main phases; a swing phase (40%) and stance phase (about 60%). The stance phase can be further broken down into: [1]initial (heel) contact, [2]loading response, [3]mid-stance, [4]terminal stance (with heel rise) and finally, [5]toe-off (terminal stance) (47). The swing phase is when the limb is out of contact with the ground and clears the ground as it prepares the limb for its following heel strike (47). A gait cycle is the reference to two steps being made and the events that occur, along with the movement components of the LE, are shown in *Appendix I – Figure 14* (47).

During walking, rotation of the pelvis causes a rotation of the tibia and fibula (the magnitude of this rotation increases as it goes to the more distal limbs). IR occurs in the swing and early stance phase, then ER occurs from then until the stance phases completes before take-off (47). The foot-ankle complex has to perform 3 main functions that is required in all dynamic movements and that is to be; [1]flexible to allow for adaptability to the different terrain, [2]semi-rigid to act as an optimal spring for the push-off phases of gait and [3]rigid to enable a high stability in order to withstand the BW and ground reaction forces (47, 48).

At initial (heel) contact, the foot contacts the ground in supination (the calcaneus is in an inverted position) and this mechanism 'locks' the forefoot and mid-tarsal joints causing it to be rigid to absorb the ground reaction forces (48). After the initial strike, the rearfoot then begins to move into pronation, as the talus rolls medially, 'unlocking' the forefoot and creating a shock absorption (48) and lengthening the MLA (47). In a normal foot, this pronation occurs during the first 25% of the stance phase and the flexibility of the mid-tarsal joints allows the foot to adapt to the ground more easily (49). In the late stance phase, the foot must act as a rigid lever again, therefore it is further supinated (48, 49). Here, the inverter muscles aid in initiating the inversion at the calcaneus to reproduce the supination and ER of the tibia. With the activation of these muscles, the MLA is lengthened momentarily, right before the windlass mechanism occurs (from the DF of the toes), causing it to shorten at toe-off (47, 49). This pathway and pattern of the foot in gait is characterized as a physiological roll-over and ‘mature gait’. For a more comprensive review of the dynamic biomechanics of the lower extremities in both walking and running, refer to *Rodgers M. (1988)* review article (47).

In the view of FF where the MLA is lengthened, the subtalar joint is pronated throughout the phases described above, leaving the foot joints mobile instead of rigid (49). There is eversion of the calcaneus which in turn, decreases the inclination of the subtalar joint axis of rotation and results in increased forefoot DF and decreased ADD (50). This affects the shock absorption at midstance and also causes a delay in the resupination in late stance phase as the windlass mechanism is compromised. Therefore to propel the body forward, more muscle action is required to aid in arch support and higher stresses are being placed on the plantar ligaments (48, 49). As a kinetic chain response to the abnormal pronation, the tibia is also affected and rotates medially, forcing the knee into valgus (48).

Despite having noted the effect of a flattened MLA on the subtalar joint, which is easily assumed with the knowledge of biomechanics and theoretically supported also by mechanisms such as the midtarsal locking and windlass, the effect of arch height on the kinematics of the foot is still unjustifiable. According to findings from a study’s assessment of arch height on kinematic coupling in walking, only calcaneal coupling ratios (calcaneal eversion/ forefoot ABD and calcaneal eversion/ ABD) were associated with arch height and the arch height explained just 38% of the variance. This reveals a small relationship of the arch height to the intersegment coordination of the ankle and foot, however, the sample used in the study included individuals who are asymptomatic and therefore may already have developed an adaptive way to accommodate to their structure (50). Further studies are needed to support these findings in order to evaluate the relationships of these variables in symptomatic cases.

2.2.3 Gait in Children

Children exhibit many different gait patterns throughout their development because of the physiological changes (51). Conversely, some foot deformities are blamed for a delay in a child's motor development, but actually children with deformities may still walk well if their development is normal such as in the case of physiological FF. However in atypical motor development situation where it is affected by an underlying problem, their foot posture and walking is affected but correcting the foot would not correct the delay, therefore the deformity is less likely to decrease with increasing age as it would in healthy children (52).

An inefficient gait is said to be when there is failure of the foot to resupinate and externally rotate the tibia in mid to late stance phases and swing phases of gait (53). However, in children, because of the physiological presence of FF, this can be viewed as a 'normal' variant of gait, when there is no underlying pathological cause (51). It is important to know the sequence of motor development in children to be able to assess what is 'normal' and what is considered 'abnormal' when looking at the alterations of gait as it complexly involves all the aspects of the lower limbs working together.

When children start walking, around 1 year of age, they walk with a wide base and FF. They may also develop toe-walking until about 2-3 years of age where their gait patterns start to mature and change (51). Children also walk often with the presence of genu varum, because of the torsional changes that occur in the lower limbs, which then turns to genu valgus (around 2 years of age) until it neutralizes spontaneously around 7 years of age (51). When there is a large ER at the hip present, a more out-toeing gait is likely especially in the younger child, and an in-toeing gait from IR of the tibia and/or femoral anteversion is more likely in toddlers (51).

Many studies have identified age-related differences in kinematic and kinetic gait parameters within a range of age groups. Majority of them report that healthy developing children reach adult-like gait patterns from age 5-7 years and up (54). A cross-sectional study on gait parameters of children aged 1-13 years old, revealed children reaching adult-like patterns by age 6-7 in a population sample of 7788 children from cities across Germany (55). They evaluated both static and dynamic foot characteristics, finding; an increase of both length and width with age, and an increase of total contact area of the feet to more than twice as much from the youngest to the oldest groups in contrast to the arch index (AI) which declined with age (maturity of the arch) (55). After age of 8 years, the length continued to increase but the width began decreasing resulting in narrower feet appearances. The AI appeared to decline the most between ages 1-6 and after that remaining on a constant level. The highest inter-individual differences in this study lied in the midfoot region, especially within the context (55). Another similar study involving comparison of gait parameters also identified some age-related differences, between 3-13 year olds (54). From their reports, significant differences were found in the gait cycle time, cadence and walking velocity between the age groups. The youngest group (3-4 year olds) had a shorter cycle time and higher cadence with a mean of 146.6 steps/min, in comparison to the oldest group who had a cadence with a mean of 120.21 steps/min. The walking velocity appeared to increase with age as well. The youngest group also demonstrated an increase in hip and knee flexion and ankle PF during the swing phases of gait but statistically, it was not significant (54). Adult-like gait kinetics began to appear from the age 5 onwards in this study, however, the peak PF moments at the ankle during late stance phases did not reach adult-like magnitudes until age 9 and above, as well as power absorption and generation (54). From the conclusions of both these studies, it can be drawn out that by the age of approximately 5 years, children's' gait begins to mature more into the adult-like gait, however with some parameters that don't evolve until later because of the continuous development of the musculoskeletal and central nervous system (CNS) as a whole.

One of the studies didn't show adult-like power generation and absorption for the PF moment in late stance phase until the age 9 and this may be due to the lack of muscular strength available in younger children (54). One of the slowest subsystems to stabilize, in a typical development, is the muscle activation patterns. Published EMG data from a longitudinal study of 8 typically developing toddlers showed that there is a shift from the use of excessive muscle activity in the leg muscles to more stable adult-like patterns by 3 years of age (56). However the authors also noted that stable patterns emerge only when behaviors have been practiced sufficiently. Even though the muscles had shown less variability and coactivation as walking experience increased, they were barely consistent (56).

The most common gait alteration in children is subtalar pronation due to the presence of the physiological, flexible flat foot (FFF) as the arch is still in development (57). The significance of the gait changes caused by FFF is questionable in clinical practice, as it spontaneously resolves itself with age according to its natural history however gait deviations are known to cause LE pathologies in later life. Studies began to evaluate and compare LE kinematics in children with and without FF to learn whether or not there are major and significant differences between them. Children do exhibit different foot kinematics when they suffer from FF in comparison to those without the deformity (58). Those with FF walk slower and recorded greater ABD and ER at the ankle and knee joints, specifically in the stance phase, as seen in one study examining FFF kinematics (33). On the contrary, a Taiwanese research provided kinematic data differences between 20 children with and 10 without FFF (with a mean age of 9.7 years) and concluded no results of the movement patterns similar and no significant differences present in any variable (57). They reported though, a much larger calcaneal eversion position in static standing of the children with FFF, but during walking, there were similar movements of the rearfoot in both groups. The authors suggested this may be due to the discrepancy to different loading conditions or coupling kinematics (57). The study lacked significant differences, maybe due to the inconsideration of the midfoot and forefoot (only the hip, knee and rearfoot were evaluated). However the FFF had a tendency towards a higher knee IR in the transverse plane, hip F and ADD in the stance phases of gait (57).

In one study evaluated only kinematic data, 24 children (age range 11-12 years) were randomly selected and divided equally, according to their arch classification to a low arch and normal arch groups (58). The feet of the children were flexible and asymptomatic. Regarding the results of temporo-spatial parameters; there were no significant differences and these include walking speed, stride length, and step times and lengths. This appears to be a pattern, as a similar kinematic study disclosed the same outcome (59). But revelatory differences were found in the hip in both stance and swing phases of gait where the ER was higher by $6\text{-}7^0$ in the low arch group (58). They also displayed increased knee valgosity at initial heel contact but the difference was not that significant (mean difference of 1.4^0 between the groups) (58). The complete date on all 22 kinematic parameters measured can be seen in *Appendix II – Table 8* (58). In another analogous study, evaluation of a similar age group of 9-12 year old children for kinematic foot motions with a larger population of 25 children with a normal arch and 27 with FFF was done (59). With more information collected on the ROM of the ankle joints, the results revealed a normal subtalar ROM to be 6^0, and in FF to be 9^0 in walking. The MLA angle in the flat-footed group was approximately 10^0 larger than the normal arched. The flat-footed group also displayed a decrease of pronation of the forefoot and an increase in ABD with no ability to ADD the forefoot in gait but only on the left side (59). The decrease of ADD in the forefoot is a common finding in children with FF, but the study revealed asymmetrical results.

The results of kinematic studies are found to be variable from the use of different age groups, classification methods of the feet, severity of FF analyzed and their methods of analysis (57). Most of these types of analysis are on adult populations also (59). In conclusion however, it is seen that the presence of FF in children does in fact significantly alter LE kinematics (58), with the most common findings being in the rearfoot and forefoot, with higher eversion and abducted positions, and also tendencies towards hip ER and knee valgosity. Majority of these studies also investigate only kinematic variables without considering the role of muscles and other kinetic data and further studies are needed to evaluate kinematic and kinetic variables in combination to demonstrate a broader view of the effect of foot posture on gait. The importance for this can be seen from the results of a study that evaluated vertical ground reaction force distributions of individuals with high and low arches (60). A foot arch structure model, that can be viewed in *Appendix I – Figure 15*, was used to analyze how the two types of arches are affected by loading (60). They suggested an increase of muscle tension of LE in FF because of the VGRF as there were significant differences in the distribution of plantar VGRF between the two groups. It can be assumed that it is the reason for faster fatigue in people with FF. However the subjects were divided into groups of either high or low arched and no comparison to normal arched individuals was made (60).

2.2.4 Implications of FF on Gait and Posture

The MLA is essential for optimal foot function, an increase or decrease of its height from the norm impairs its function and causes muscle imbalances, joint malalignments and gait disturbance (17). A low arch is normally looked at as a deformity amongst adults but in children, a low or flat MLA is considered physiological. In the first years of life, it corresponds to lack of ligament tightness, lack of muscle strength, immaturity of the CNS and development and growth of the structures of the foot. As a result of that, it normally corrects itself in the first decade of life with increase of age (29). It has been reported however, that about 15% of the population maintain the flat arch (57). Numerous researches conducted that FF, specifically the flexible type, rarely cause disability, but recent studies began to challenge this by investigating its relation to pain and injury by implementing studies with symptomatic subjects (58).

It's been noted that low arches cause changes in alignments, in all populations. The presence of overpronation of the ankle causes the tibia to internally rotate, the knee to go into a valgus position, hips to adduct along with tightening of the muscles and external rotators to weaken (48). In connection with these alignment changes, low arches may become symptomatic and have been associated with soft tissue injuries such as plantar fasciitis, patellar tendinitis, tensor fascia latae syndrome, metatarsalgia, and others such as hallux valgus, osteoarthritis (OA) (specially of the midfoot), and posterior tibialis dysfunction when progressing into adulthood (61, 62). It also increases the risk of injuries in activities and sport because of the altered mechanics.

A report of 40 runners, half with extremely high arches and half with extremely low, provided information about their history of musculoskeletal injuries and several injury profiles were created and this can be seen in *Appendix II – Table 9* (63). Even though the results of data collected from the study demonstrated that the low arched runners have more tibial IR and eversion at the ankle in stance phase, the injury report presents the low arched runners at more risk for knee injuries and the high-arched for ankle/foot injuries (63). In the loading phase of the gait, the flat-arched displayed higher ER at the knee with femoral IR and this causes an increase in the quadriceps angle therefore with an increase of force from the muscles whilst the patella is displaced laterally may be the reason for the higher risk of knee injuries (63). The high-arched subjects that were a part of this investigation had higher vertical loading rates which explain the increase of injuries at the ankle. A study on inversion sprains of the ankle also commented on the high incidence of this particular injury in individuals with high arches, from the position of the ankle at ground contact phase (64). Contrary to these results, in a similar study, arch flattening in 34 runners was measured with video analysis and force plates to examine the effect of VGRF's and the differences it has on the different arch heights (65). No significant differences were caused by the VGRF in the different arches, but the authors put forward the theory that it may be due to the runners' own adaptation mechanisms of running such as increasing knee F at touchdown to decrease vertical impact (65).

In the topic of adaptation, many cases of FF remain asymptomatic because of compensatory mechanisms that occur (48). These compensatory disorders however can affect the biomechanics of the LE greatly and may increase the risk of developing them into structural deformities and rather than just functional ones, and affect more proximal areas (48). This relation may be regarded as bi-directional as there are many proximal deformities or dysfunctions that compensate by abnormal pronation at the subtalar joint, leading to flattening of the arch and this occurs mainly in adults but may also occur in children that have resolved their physiological FF. Causes of such abnormal pronation are compensated forefoot valgus, muscle imbalances, congenital calcaneovalgus, torsional imbalances and any other factors that increase WB medially (66). So a biomechanical change such as an IR of the hip has the capability in generating a medial weight-bearing moment at the subtalar joint subsequently causing pronation (67).

In a clinical practice guideline (CPG) for management of adult FF, it was highlighted that adult FFF is most commonly a progression of pediatric condition and is associated with a short Achilles tendon frequently (and tibialis posterior dysfunction) (66). It also presented that symptoms and pathogenesis of FF is usually from structural loading changes and become symptomatic because of overuse pain and fatigue (66). It is possible that if changes made in childhood to prevent the FF developing into a more permanent deformity can decrease the chances of it persisting into adulthood, and given that it's common for the deformity to be structural, preventive measures should include ways in improving alignment and muscle imbalances. The persistence of FF into adulthood as a pediatric residual is more often than realized. 53 Italian children with a previous diagnosis of FFF were included in a consecutive case study (ages 10-14 years) and were evaluated systematically with an interview and physical assessment (61). Results were very surprising, revealing that 65.3% of the sample were symptomatic and that 68.3% had related functional problems mostly in sports and some activities of daily living (ADL). Moreover, 54% of the children had FFF and the rest were rigid (high number). The symptoms were related to knee alignment significantly (IR presence was common) and symptoms also correlated with high BMI and females (61). Functional limitations correlated with heel valgosity, however as the footprints were analyzed, results showed that 93.1% of them were enlarged but only 83% of the population displayed heel valgus positions of the feet (61). This was a study based on an age group that supposedly should not have symptomatic forms or rigid forms of FF as they were a little over past their critical developmental period, yet there was a high number of limitations and symptomatic cases that involve tiredness, pain on the plantar aspect of the foot and discomfort, which are all common symptoms seen in adult FF. A FFF assessment should not rely only on static tests and morphology but should be functionally defined (61). An interesting finding in the study was a decreased DF ROM that correlated with age as well, due to the shortening of the Achilles tendon. It's explained that during growth, the tendon tries to accommodate to the heel valgus and therefore as a consequence, can cause FF as well as be the consequence of FF deformity (61). If early intervention is commenced and maintained, such problems can be prevented.

While this proposed link between foot posture and risk of injury appears to exist, the results of prospective studies didn't provide definitive evidence to support it, according to a systematic review of 12 articles that compared FF with normal foot postures (68). The review though concluded some good evidence available that points towards increase of EMG amplitudes for invertor muscles (tibialis posterior) and decrease of amplitudes for evertor muscles (peroneus longus) in the low-arched individuals (68). However, the populations in those studies can't be generalized and the best evidence suggesting these results was using older adults with rheumatoid arthritis (68, 69). The same authors of the review sought out to prove the findings by examining EMG results of LE muscles in gait of 60 healthy young adults (divided equally into low arch and normal arch groups) (69). The results were the same, showing that the tibialis posterior had an increased activity whilst the peroneus longus had a decreased activity in the mid to late stance phases of gait. Findings also presented that at heel contact phase, peroneus longus muscle activity still remains low and the tibialis activity increases which brought the authors' explanation of the peroneus longus muscle working less as a means of protecting the arch from overload, or that the FF is less laterally stable, not requiring much activity from the muscle (69).

FF has also been correlated with not only ankle/foot and knee problems but also changes in the pelvic alignment and low back pain (LBP) (67). The foot's contribution to changes in pelvic alignment lies in its connection to the proximal areas of the lower limb and upper body via the muscle kinetic chains. As pronation of the foot, which is in FF, causes an IR of the lower leg and femur, the pelvis is moved to anteversion. A literature review evaluated articles regarding foot motion and lumbo-pelvic hip function however it is evidence found in adults only (67). It was hypothesized that altered positions of the pelvis to anteversion from excessive pronation increases strain on muscles such as the iliopsoas, piriformis and gluteals (67, 70). This connection has further been evaluated by studies that attempted to simulate hyperpronation in healthy subjects by using sloped wedges or platforms of varying degrees to cause eversion of the ankle joint in standing. In a study with such a method, 35 healthy subjects (aged 23-33 years) were asked to stand for 10s each on bases of support at different angles (71). Tibial alignment significantly increased to IR corresponding to the increase of calcaneal eversion produced. There was also an increase to IR of the thigh and of anterior pelvic tilt (which showed a significant difference between standing on the ground to standing with a 10^0 eversion) (71). An illustration of the proposed reaction can be seen in *Appendix I – Figure 16* (103). However, when the subjects stood on the steepest wedge, no significant changes in the pelvis was seen, which may mean an optimum alteration has been reached by the pelvis. Small changes of the pelvis alignment to anterior tilt are assumed to be enough to cause large functional changes in standing and walking (71). The other study with a similar method of examination, evaluated the changes of the eversion on the proximal body parts in unilateral WB (70). It was expected that because unilateral WB is common in frequent activities, the influence may have a stronger effect on the proximal segments (70). In contrast to the bilateral condition, unilateral hip F was accompanied by more posterior tilting of the pelvis in standing, therefore ankle eversion unilaterally can't induce a larger anterior tilt than in bilateral WB (70). The thoracic segments were additionally evaluated in the study and as eversion was increased, the segments tilted and rotated towards the stance side however pelvis rotation did not increase. The outcome of the study may indicate a risk factor for LBP, specifically for unilateral WB activities but a limitation to the study was that only immediate effects were assessed, and in healthy subjects (70).

Another study involving the use of platforms to alter the biomechanics of healthy individuals involved 18 different foot positions (72). The lumbar spine and pelvis were analyzed for changes as the participants stood on platforms varying from 15^0 of eversion to 15^0 of inversion and 40^0 of ER to IR of the foot. The subtalar pronation demonstrated IR of the tibia and femur but no changes in the pelvis and lumbar spine were seen with inversion/eversion and as the authors speculated that the ROM may be too small, a rotation component of the lower limb was added and assessed. The IR of the lower legs caused an anterior tilt but no changes were seen in lumbar spine nonetheless (72). It was further speculated that the lack of changes seen in the pelvic posture may be because the healthy partakers of the study may have been able to use short-term compensatory mechanisms to prevent changes in proximal areas (72).

A review on foot function and LBP searched the variety of mechanisms where the foot may affect the low back through an extensive literature review. Refer to *Appendix II – Table 10* to see the different theoretical mechanisms that explain a relation between the two (73). An investigation that was cited in the review on chronic LBP showed appealing results. 97 participants that were included in the study suffered from chronic LBP and 81 of them had presence of overpronation (73). They were treated with foot orthoses and manipulation, and at a 6 month follow-up almost all the individuals related an almost complete lessening of their LBP symptoms. The development of LBP (in connection to foot pronation) can be a result of 2 factors: [1]IR of the LE in gait and [2]inadequate shock absorption as seen in FF (73).

An increasing number of studies recently began to investigate plantar pressure variables. Plantar pressures (PP) have been used to characterize dynamic functions of the foot (62). The variance of PP are affected by several factors such as body weight, shape of bones, integrity of soft tissues, gait dynamics and muscle functions (62, 74). Increases of PP, according to researches, are related to diabetic ulceration, hallux valgus, midfoot OA and more disorders, but cause-effect relationships have not been made clear (62, 75). A study attempted to learn what the structural or functional predictors of PP under the foot are (75). Many variables were evaluated such as anthropometric measures, ROM, radiographic parameters, and EMG's of muscles. 55 asymptomatic subjects were included with the age ranging from 20-70 years. Results concluded that for the midfoot, the magnitude of the pressure was most predicted by structure, mass (increase of mass increases PP) and age (increase of age decreases PP). Low arches produced an increase of PP under the midfoot, and also the more available eversion ROM, the less PP (75). Another study investigating PP in the midfoot compared its association with the measures; arch index (AI), navicular drop and navicular drift (62). It included 92 healthy adults from Alaska that were measured in standing and walking. The low arched subjects displayed lower PP in the medial forefoot but high PP under the hallux in midstance phase of gait. No relation of the rearfoot PP and the MLA was found but only the medial aspects of the feet were evaluated (62). In the previously mentioned study that investigated functional and static predictors of PP, results for the rearfoot demonstrated that an increase of MLA height increased PP in the region and that the higher presence of soft tissue under the calcaneus the lower the PP are as well (75).

An interesting research on foot ground pressures of FFF in children was done to compare the PP with and without correction of the deformity (74). A study sample of 4-6 year old children was used, with similar foot characteristics. Amount of load beneath the soles of the feet were measured without then with correction (by a medial heel wedge) and the patterns were divided to anterior, posterior and middle WB areas. In normal feet, posterior WB is usually 61%, anterior is 35% and middle is 4% (however this increases with FFF). The subjects of this study gave the results of posterior WB as 54%, anteriorly 29% and middle WB 17% to as high as 30% (74). For the WB of the midfoot this shows a large increase for the children with FFF and after corrections were made, the WB was almost decreased to normal (down to 6% in middle WB) (74). Plantar pressures can provide very useful information, as seen above, for severity of FF and the impact it has on loading changes of the foot and it could also be clinically significant in treatment when providing orthotic treatment.

Information from PP is also useful in detecting gait pathway patterns. In a normal pathway of PP in walking, WB moves from the lateral heel, medially in the forefoot towards the big toe however in FF the pathway moves directly from the heel to toe (76). A study reviewed the implications of plantar foot pressures in childrens' gait. Only 9 subjects with FF were compared with 10 subjects with normal arches. The PP under the 1st 3 metatarsals (MT's) increased in FF, especially under the 2nd and 3rd MT bones and the PP decreased under the 4th and 5th MT significantly. The midfoot PP in comparison of both groups proved to be quite similar, except that the loading was more medial in the FF group (76). This could explain that the increase of PP in FF is from a decrease of PP on the lateral region of the foot from change of centre of mass direction and not from increase of PP on the medial surface (76). An analysis of the functional adaptation of MT bones was made in adults with symptomatic matarsalgia compared with adults with asymptomatic feet (77). Parallel to the results above of the PP under the MT's, the results of this study had significant differences for the 1st and 2nd MT's dorsal cortical thickness, especially under the 2nd MT where the increase was 18.1% greater than in the feet of asymptomatic adults (77). It can be concluded that the MT bones have the largest adaptive response to increases of load and forces upon the foot.

2.3 Pes Planus in Children

There are many synonyms that are used to describe FF, such as; pes planus, calcaneovalgus, planovalgus, pronated foot and so on (78). FF is well known as a postural deformity. It occurs in 10-23% of the general population (79). In pediatrics, it's one of the most commonly negotiated topics when it comes to problems of the lower extremities, and it is also the most common reason for referral to an orthopedic (ORT) consult (80).

Until present time, given its frequent presentation, there's no universally accepted definition of FF or what exactly constitutes it (81). The term has been used extensively and for a long time now in literature with a large difference in definitions (82). Pes planus is more of a description of a medical condition, that's defined more or less subjectively as a lowered or absent MLA within a population, rather than a strict diagnosis with an underlying cause (12, 82, 83). This description could surround a non/pathologic or non/symptomatic condition (82). It's more of a reference of a clinical deformity which could exist in isolation, or be part of a larger clinical entity (12, 90).

When flat feet are seen in children, it's referred to as 'pediatric flatfeet' (84). Children are born with FF and in the first few years of life, FF is present and physiological. FF is normally a developmental deformity, but it can also be acquired (especially in adults). It's characterized by a lowered MLA and a valgus position of the heel (76). Apart from those common attributes, there are anatomic characteristics of FF that are well known, such as those adopted by Mosca[81] that are: eversion of the subtalar joint in WB, PF of the calcaneus (in relation to tibia), PF of the talus and a supinated forefoot with an ABD navicular (81). These may all or may not all present in a patient with FF and usually depends on the deformity's severity.

Screenings for foot problems in children, as early as 1960's, always showed a large prevalence of FF, especially those below 6 years of age but this is now seen as an expected part of development (85). Despite this change of opinion, it has been and still is a major concern for parents to consult a doctor for, with worry about their child's development (32, 78, 86).

Findings from prevalence studies for FF across a variety of age groups measure about 45% in preschool aged children, and 15% with a mean age of 10 years (85). However it is higher with hypermobility, increased weight, male gender, neuromuscular disorders, positive family history and other factors that will be discussed later (85). A large recent Cochrane review found 15 studies regarding the prevalence of FF (78). Their summaries can be found in *Appendix II - Table 4*. To highlight different results, from the 2 most appropriate studies, prevalence for 3-6 year olds was found to be 44% (n=835) and in an older age group of the mean age 9.2, results were 17.2% (n= 579) with moderate to severe FF (78). A study done by Morley et. al[83] evaluated the incidence of FF in children from 1-10 years and found that almost all the 2 year olds were flat-footed but only 4% of the 10 year olds were (83).

Most infants' arches do develop spontaneously in the first decade of life but this again changes in adulthood where about 15-20% of adults have asymptomatic FF (14). There will always be a large variability of normative values for a developing foot that is age specific, but very often in studies that evaluate that, they find that the values eventually change to match adult norms with time (83).

Previous studies reported a large amount of unnecessary referrals to use treatments for children's FF. A comparative survey study aimed to see the influence those studies have made in daily practice, if at all, and on physicians' approaches to diagnosing and treating pediatric FF (80). Two large surveys were done in the Dutch populations general practice, one in 1987 and another in 2001 of over 80,000 children aged 0-17 years (80). The incidence for FF decreased from 4.9 per 1000 person-years, in 1987 to 3.4. Also, the rate of referrals decreased from 38.3% of the children being referred in 1987 to 22.5% in 2001. The influence of the studies have possibly made this difference and impact in practice, shown clearly in those results, however it is limited to the Dutch population (80). Even though there is no true accepted definition of flat feet, improvements are always being made, from the aid of evidence-based literature, to help distinguishing the normal development to abnormal or pathological and which types are more necessary to treat or not. There is, however, a wide range of variability in children's FF and it's what makes it difficult to distinguish normal from abnormal and this is also why it raises the concerns of parents when it comes to their child's development (55, 82).

2.3.1 Classification of Pes Planus

Acquired vs. Congenital: Pes planus can have a congenital (when present from birth) cause, as seen in problems such as tarsal coalition, congenital steep talus and vertical talus. However it is commonly more *acquired*, due to faulty development and in most cases continues into adulthood. It can also be acquired from injury/trauma (ex. Arthritis), or an illness (Ehlers-Danlos syndrome), muscle weakness/imbalance (as in CP), contractures (peroneal spastic flat feet), aging, and so on. When it appears in adulthood it is called adult acquired flat feet (87, 88).

Physiological (developmental) vs. Non-physiological: The physiological FF is developmental and has a lot of contributing factors affecting it (32). It is seen as a normal part of a child's growth and development and resolves itself spontaneously with age. The non physiological FF worsens with time instead, and needs more detailed examinations. Frequently, the etiology of it falls into one of the 4 main subgroups; neurological, muscular, genetics collagen, or it can also be associated with trauma, predispositions or other ORT disorders (78).

Symptomatic vs. Asymptomatic: People with fallen arches sometimes, even when non-physiological, remain asymptomatic (without symptoms). This is because the foot adapts to the structural deformity by changing the shape of the bones and stretching of the ligaments in the foot. However, even if they are asymptomatic, the changes still affect the normal biomechanics of the lower extremity especially if the FF is of a pathological origin and they can nevertheless develop into painful FF and further to rigid ones (48, 55, 78, 89). Symptomatic feet are normally associated with other conditions (89).

Flexible FF (FFF) vs Rigid FF: One of the most important considerations is whether the foot is rigid or flexible (82). Flexible FF is a term used for when the arch is present in an off-WB position, but lost in a WB position (81). Asymptomatic FFF is either physiological (improves with time) or non-physiological (progresses with time) (90). In the case it is symptomatic, it produces altered function, complaints and objective findings and is usually treated accordingly (14, 90). It's said to be caused or be a part of a generalized manifestation of a ligament laxity (14, 30).

Rigid FF is often caused by changes in bone structure and can occur pathologically or idiopathically (14). It often leads to pain and disability if left untreated, and surgery is sometimes necessary (14, 32). It’s characterized by a loss of the arch in both open and closed kinetic chain movements (81), and a valgus position of the calcaneus, pronation of the midfoot, medially oriented talus and a laterally-dislocated navicular bone (14). It has many etiologies that could be placed in one of the 4 main subgroups mentioned earlier (14, 78).

The foot is the most affected region when it comes to changes in anatomy of the body and the structure with the highest variability in the foot is the MLA (86).

2.3.2 Diagnosis

The most frequent reasons for examining the foot in its developmental period are; pain, deformity and/or incorrect gait (91).

One of the first considerations in diagnosing the deformity is the age of the patient. At birth, there is a presence of calcaneovalgus and no MLA seems to be present. The MLA grows and develops gradually with age, as part of the development process, and with increase of strength, size of the foot structures and increase in motor skills, the FF resolves itself (55, 84). By the walking age of 12-18 months, there is still no MLA visible and this is due to the presence of a characteristic that differs children's FF to an adults, which is a fat pad in a child's midfoot area (until 2-3 years approximately) that acts as a protective adaptation (52, 55). Therefore children may show flatfeet presence in weight-bearing positions with pronation of the foot and valgus position of the ankle (84). The fat pad gets reabsorbed spontaneously, around 3 years of age, as the muscular system adapts enough for the upright gait (55) and it is because of this reason that diagnosis is best made at 3-4 years of life, after this resorption (89).

Also, a very important part of diagnosing FF in children is history taking. There are several significant history areas that aid in diagnosing the type of FF such as the age of onset, presence of other medical conditions, symptoms if present and what they are, a family history, previous trauma, the child's activity level and the sequel of development (if it is following a normal path or if it's worsening) (90). A collaboration of findings from the history and clinical observation (along with results of imaging procedures if necessary) results in a final diagnosis. The diagnosis usually falls under one of these categories; 1)flexible FF, 2)rigid FF: congenital vertical talus, peroneal spastic FF, tarsal coalition, iatrogenic and posttraumatic, 3)skewfoot, or 4)other less frequent causes (90).

There are several approaches and clinical practice guidelines that have been developed with evidence-based approaches from up to date literature reviews and current clinical practices, to aid with diagnosing and managing pediatric FF. A recent Australian study has created a new pediatric-FF proforma with this approach. The proforma is a clinical care pathway, and has 29 items less than the original FFP after a reliability assessment (92). It can be viewed in *Appendix II - Table 5*, and it highlights the most important areas to be aware of in diagnosing and treating FF in children, taken from current evidence. However, it has been built using an older age group of 7-10 year old children only (92). As for detailed examinations on diagnosing FF in children the reader can look to the American Pediatric FF Panel clinical guideline (90) or a detailed review about the examination of the foot in the developmental period (91). The CPG contains a framework for diagnosing FF in children, showing the most significant findings to look for when examining, and also highlights several treatment options. The framework for diagnosing FF can be seen in *Appendix I - Figure 12 and 13* (90).

Classification of the MLA

There exist many classification systems for evaluating the foot structure, and its relation to foot function (93). The reliability and validity of these systems however, vary and are still in dispute. Attempts at classification have focused majorly on arch height (MLA), heel eversion angle and if the foot is rigid or flexible (78).

The MLA has become a main reference in diagnosing FF (94). Several methods have been utilized to identify and classify the MLA, such as using clinical signs, radiographs, footprint analysis' and so on (95). The use of clinical criteria for diagnosis was the first form of classifying the MLA, with a specific observation of the foot in stance and sitting positions, position of the foot bones and the heel and some special tests.

Since 1952, uses of quantitative measures increased to support or moreover replace the common clinical diagnosis (which was believed to be generally subjective, requiring experienced clinicians). Quantitative methods were initiated by the use of the Harris and Beath footprint mats and the development of the valgus index (96). In a critical literature review, it was stated that methods of classification that are based on foot morphology in general, can be placed into one of the following categories: [1]Visual inspection, [2]Anthropometric values, [3]Footprint parameters and [4]Radiographic evaluation (93).

Details on classification of FF and its diagnosis is beyond the scope of this literature review, however definitions and several types of methods that are mainly used will be discussed in the forthcoming section for each category.

2.3.2.1 Visual inspection

A visual observation is part of a routine practice and is always used for typical examinations. Visual inspection is usually enough to classify a flexible foot from a non-flexible FF (93).

There are characteristics that mainly exist in the FF deformity or aid the diagnosis of FF when observed and these are (16, 97, 98);

- Mainly the presence of the fallen arch
- The head of the talus is displaced medially and plantarward from the navicular putting the spring ligament on a stretch, as well as the tibialis posterior muscle
- Prominent talar head medially, and eversion of the calcaneus
- Hyper-pronation of the foot (ankle rolls inwards)
- More weight distribution to the inside of the sole (ankle in valgus position)
- Medial column longer than lateral column (*appears* to be)

Inspection of the posture is done in all directions, and also includes some special tests such as tip toe standing and great toe extension and examining the foot in WB or non-WB positions to differentiate a rigid FF from a flexible foot (93). Testing for FF should always be dynamic and not only static as it is a functional deformity (52). Variations of walking, with and without shoes, are also observed. During a gait observation, it's important to take note of the medial borders of the feet, foot progression angle, the calcaneal eversion (average rearfoot angle is 4^0 valgus), heel-to-toe contact, position of other joints such as the knee and hip, and the presence of a limp (78, 90). Children may or may not confess to having pain, therefore observing markers such as altered gait, and a change in their activity level can give the physician information about pain being present (82). Associated conditions are also important such as other LE malalignments since the connection of FF to other parts of the LE is increasing in awareness (82). A recent study published in the Foot and Ankle International showed positive correlations of FF and anterior knee pain with low back pain, and the adolescents with moderate to severe FF had nearly 2x the rate of FF as the adolescents without it (82). Assessment of the ROM of the LE also provides useful information on asymmetries present.

As mentioned previously, the results primarily from visual inspection can be unreliable because of the large variability that exists amongst examiners. For quantification, the use of markers on bony landmarks or important areas can increase the accuracy. Podoscopes are also sometimes used to increase subjectivity, or even photographic documentation for record keeping (93). According to the Australian study that created the new FF-proforma, the Foot Posture Index (FPI-6) is a reliable and valid method for diagnosing FF (6> = FF) (92). It consists of; talar head palpation and examining the calcaneal frontal plane position, supra/infra lateral malleolar curvatures, the prominency of sustentaculum tali, the congruence of the MLA, and ABD/ADD positions of the forefoot on the rearfoot (78). It is evaluated in standing and its values range from -2 to +2 for each of the criteria (total score ranges from -12 to +12). The scores indicate the position of the foot along the supinated to pronated continuum of the foot posture (a negative score or a positive score respectively) (99).

A thorough clinical diagnosis criterion is sometimes said to be a gold standard in diagnosing FF, as there is still no universally accepted definition for MLA height in different age groups (95). For every country there are slight differences in the criteria provided by their ORT associations, and to what extent is a pathological or non pathological FF also differs. There is still a need for a criterion that can be used universally with clear definitions what's a norm or what is not.

An example of a classification of FF by the German ORT association is that a flexible FF is when the deformity has the ankle in valgus position (rearfoot angle) of less than 20 degrees, an where active correction is possible (by standing on tip toes or extension of the toes) and a pathological FF is when the valgosity is above 20 degrees with or without a disability for compensation of the valgus position (32). A combination of the use of observation and an anthropometric measure can be seen, and that is typical of many criteria's where combinations of methods are used and never just visual observation solely.

2.3.2.2 Anthropometric values

Anthropometric measures are used to characterize the external structure of the foot (100). It gives information on sagittal and frontal planes of the foot segments (93). Examples of these measures are the normal length and width measures of the different foot areas to determine their size and proportions.

A common measure is the arch height, which is measured from the highest point of the MLA (prominent navicular) to the ground (93). A ruler or caliper can be used (12). This is a good objective approach; however its limitation lies in the fact that it only provides static information of the foot.

The longitudinal arch angle (also known as Feiss line) is also a common reliable measure. It is the angle from the medial malleolus to the navicular tuberosity, then through to the medial aspect of the 1^{st} MT head – it's an indirect measure of arch height (93).

Another is the rearfoot angle (mentioned previously) that shows eversion/inversion. It uses the Achilles bisection as the reference because it is always perpendicular to the surface, whether the foot is in valgus or not (32). The navicular drop measure, tells us about the displacement of the navicular from a non-WB position to a 50% of WB position and the valgus index (which was the first initiated quantitative measure) measures if the malleoli are more medial or more lateral in relation to the calcaneus (a positive index equals to a medial shift and vice versa) (93).

Look to *Appendix II - Tables 1 and 2* which show schemes of classifications adopted by different authors that are based on the structure and alignment characteristics and use a combination of observation and anthropometric methods (93).

2.3.2.3 Footprint analysis

Footprints are a quick, simple and cost-effective technique (17, 95). They are done from the imprints of feet taken from ink pads or pressure mats (93). The concept behind a footprint is that a higher MLA leaves a narrower isthmus print when compared to a lower MLA, which flattens the cavity and leaves a wider isthmus (27). Therefore the width area or contact area of the foot provides a clear, simple objective mean for foot classification (93, 96). It also can provide a record of pressure distribution that can be taken in static and/or dynamic situations (96). Dynamic pressure variables are very useful in characterizing and evaluating the function of the foot in activities, rather than in static posture (101). Pressures can also express the potential damage that could occur in the tissues as a result of different loading and that is used when for example evaluating the effect of obesity on the foot (101). In walking prints, areas of higher pressure under the big toe, the 1st MT and 2nd MT, medial area of the heel and midfoot are common findings in hyper-pronation (96).

There are some classification systems that can be used just from an observation of footprints to classify the feet into low, normal, or high arched. An example of this is the Denis grading seen and used in some studies, which divides the classification of FF into grades 1-3, where 1 is normal and 2 and 3 are flat (26);

- Grade 1 is when the support of the lateral edge of the foot is ½ of that of the MT support.

- Grade 2 is where the support of the central zone and the forefoot are equal, and

- Grade 3 is where the support of the central zone is greater than the width of the MT support (flattest grade).

With more quantification and measures, than the simple criteria described by Denis[14] above, many footprint indices have been developed and widely used and a few will be mentioned below (93):

- The arch index (AI), which was developed by authors Cavanagh and Rodgers[64], is the calculated ratio between the areas of contact of different parts of a toeless footprint (93). Look to *Appendix I - Figure 6* for an illustration of the index (17). The AI is classified into the following 3 categories: [1]elevated MLA is an AI < 0.21, [2]a normal MLA is 0.22 < AI < 0.26, and [3]a low MLA is an AI > 0.26 (17).

However, as reliable as this footprint index is and its wide use, many measurements have to be taken in order to calculate it which leaves more room for errors to be made (102).

- The arch angle (aka Clarke's angle, CA) is the calculation of the angle between the medial border of the footprint and the line connecting the most medial point of the MT region and the point where the shape of the inner area of the MLA touches the MT outline of the arch (look to *Appendix I - Figure 7a* for an illustration of CA) (93, 95).

  In one study's results, CA proved to be at an advantage when seeing the influence of shoes on the foot, and also in detecting gender differences (29).

- Staheli's arch index (SI) is another index that is similar to the AI, but uses the calculation of the minimal width of the MLA with the maximum width of the heel (look to *Appendix I - Figure 7c or 8* for an illustration of SI).

  According to the Pediatric ORT Society, the norm index is always within 2 standard deviations of the populations average. SI values that are equal to or above the sum of the 2 standard deviations with the average are diagnosed as FF (86).

  A study by Staheli et. al [63] aimed to provide a range of norm values in all age groups used the SI for classifying the feet of the subjects. 441 subjects aged 1-70+ years old with normal feet participated. The mean AI was calculated for each age group and also 2 standard deviations. The results showed that the norm is very broad throughout life. In infancy the range went from 0.7-1.35 where it clearly showed that the MLA width was 1.3x the width of the heel even within the norm. After mid childhood, the norm ranged from 0.3-1.0 through to adulthood (103).

- Chippaux-Smirak Index (CSI) is calculated with the formula CSI = B/A x 100%, with 'B' being the width of the MLA region and 'A' being the width of the MT region. An illustration of this index can be seen in *Appendix I - Figure 9.* The CSI has 5 categories for classification and in this way it has an advantage:

  0% = the foot has an elevated arch, 0.1-29.9% = the arch is normal, 30-39.9% = intermediate foot arch, 40-44.9% = low arch and 45%> = FF (17).

Some studies have been done on comparison of several of these footprint indices mentioned to identify the strongest and most reliable method for MLA assessment. In one, where the experiment was to try to objectify when the MLA grows and develops in school kids (ages 3-10), a comparison of the diagnostic ability of indices AI, CSI, SI and AA was made (17). The results showed that the CSI and AI had great and accurate abilities however the AI needs special equipment and a lot of time to calculate it. Also the presence of the fat tissue in the younger age groups may mask the formation of the MLA and therefore affect the AI falsely (17). The CSI had, therefore, the better advantage. The study also showed that the SI was very different to the rest of the indices in its criteria.

In a comparative study (95), the 3 footprint measures CSI, AI and CA were used to compare each other against the gold standard clinical diagnosis criteria. The study had used 1319 preschool aged children with an average age of 62 months. From the results, cut-off points of these tests were drawn out to the diagnosis of FF in the preschool aged. These cut-off points are as follows: CA less than or equal to 14 %, CSI larger than 63% and for the AI larger than 107%. As for the comparison of the indexes, they all showed great diagnostic abilities but in agreement to the previous study mentioned, the CSI again showed the most superior performance with a predictive probability larger than 90% (95). In *Appendix II - Table 3* results from the study can be seen, where the 3 different analyses are distributed according to different age groups. In a different study, by authors Fariol F and Pascual J, cut-off points for the same indices were determined, but for higher age groups (3-17 years old) however it wasn't appropriate for the younger kids as if the same criteria would have been used, most children in this study would have been regarded as having severe FF. This highlights the importance of having norm values available for the different age groups when classifying the feet according to footprint index methods.

2.3.2.4 Radiographic measurements

Radiographs are widely for assessing foot structures. It is always recommended that painful FF in children should be immediately imaged, to rule out certain anatomical variants such as tarsal coalition (104). Apart from bony components, x-rays can clearly visualize skeletal components of the MLA. Foot characteristics, in this way, can be taken from radiographs and angles can be measured for quantification (93). The following measurements are the most frequently cited and illustrations of the parameters can also be seen in *Appendix I - Figures 10 and 11*(93):

- Calcaneal inclination angle (CIA), which is taken from a lateral X-ray is the angle between the tangent to the inferior surface of the calcaneus and the ground.
- The height-length ratio of the MLA
- The calcaneo-first MT angle is the angle subtended by the tangent to the inferior surface of the calcaneus and the line drawn along the dorsum of the 1st MT (93).

Many studies use a combination of footprints and radiographs for diagnosis, not only for comparison, but to increase preciseness of the diagnosis and to have more information available. One study that assesses the MLA in children and adults with obesity used both footprints and radiographs and found a very strong correlation between their results (94). Although there are many other studies in agreement, their reliability is still questionable, with the main reason being that they acquire 2D information only (37). Radiographs give flat images of a 3D problem, as FF includes 3D faults including hindfoot pronation, midfoot ABD, forefoot supination, subtalar joint DF with ER all in relation to the hindfoot, and not all these are visible on neither X-rays nor footprints (37). Also, another limitation of radiographs is their difficult use for children below the age of 6 approximately, because not all the ossification centers of the foot bones show until the later ages and the sustentaculum talus doesn't become visible until about the age 9-10, making it hard to draw out the axes from the X-rays (96).

This brings an ongoing debated question to whether the information about the static appearance of the foot arch is able to predict or give information about the dynamic behavior of the foot. A study by Cavanagh et al. tried to identify to what extent static foot structure variables, taken from an X-ray, would predict peak plantar pressures in walking (105). Even though the experiment was done on adult subjects, the information collected was quite influential. There was a very high reliability noted in the measures taken radiographically. More importantly, after a regression analysis, the results showed that a few structural measures *can* in fact explain about 35% of the variance in plantar pressures under the heel and especially the head of the 1st MT (105). The calcaneal height and 1st MT inclination angle were the most dominant factors (for example, the higher the MT1 inclination equals to a higher pressure under the heel) (105). Even though some studies, like the one just mentioned, believe that static measurements are correlated with dynamic ones, there are still some that concluded the opposite. This therefore marks the importance of having an index to describe the flexibility of the MLA, as well as other characteristics (37).

The first trial that attempted to measure the flexibility of the MLA used a measure called the arch volume. To measure the arch volume, a 3D laser scanner was used (37). The trial was done in Taiwan, on 44 children from ages 2-6, and their feet were scanned in sitting and one leg standing positions and anthropometric measures were also taken. As stated before in a previous chapter, there were significant differences in ages 3-4 years in the arch volumes according to this study's results, but there weren't any significant differences in ages 4-5 years, which is in accordance with another study that showed the development of the foot arch function using Contact Force Ratio's (15). However in other research, significant differences *are* found between 4-5 years of age in the MLA (17). This can be due to the different evaluation methods and whether the methods used acquired 2D information only, or also 3D information (37). 3D data may capture more details about FF and also newer insight into the problem. It may provide more accurate information since the deformity itself is 3-dimensional and more research should be done in the scope of this area.

2.3.3 Treatment

Treatment of FF has been a very controversial topic in the pediatric field. Many reviews noted the lasting debate that exists on whether or not to treat FF in children and how to treat it, especially in the FFF cases or asymptomatic cases. Given the natural developmental pattern of the arch in healthy children, the argument lies on whether it is necessary to provide a form of treatment to FF and if it would be beneficial as it would resolve spontaneously either way. It has therefore been stated most commonly that in a normal developing child, treatment procedures should not be integrated (specifically the use of orthoses) given the natural course of the arch maturation, and that it should therefore be applied to cases with painful feet, or as prevention from future disability (106). However, there are many incidents where therapy and treatment is still provided to asymptomatic FF.

An Australian study had aimed to investigate whether screening is necessary for FF in healthy children and if it would make a beneficial difference by increasing the chance of preventing it or successfully treating it (85). The study answered this by considering how well pediatric foot problems fulfill each of the WHO criteria for a screening program, and compared this to the early diagnosis of hip dysplasia. In conclusion, because of the lack of evidence for any treatment need for aymptomatic cases (which form the majority of the prevalence), or if there's a benefit in later years from it, there is no need for screening this deformity given its natural history. However for children who arrive at the end of their first decade with FF then monitoring them and treating them is worthwhile (85).

Treatment strategies are divided into conservative or surgical. Conservative treatment is always the first line of therapy for FF, even when the symptoms are mild (82). An individual approach to treatment is always best as FF has usually multiple etiologies (82). Surgical procedures are used in severe cases and in cases where the conservative therapy doesn't affect the deformity or create a positive response (82, 90). A good base of treatment comes from evidence offered by systematic reviews, clinical reviews, guidelines and studies that emphasize arch development and its influential areas (78).

2.3.3.1 Conservative treatment

Conservative methods usually involve the use of orthotic shoes, insoles, kinesiotherapy; primarily for strengthening, heel to toe walking exercises, walking on uneven surfaces, barefoot time, increasing intrinsic muscle activity such as picking up marbles, stretching of shortened muscles, the use of medicine such as NSAID's and modifying activity (89, 90, 107). For an example of therapeutic exercises used for FF, a list of exercises adopted by a perspective cohort study can be seen in *Appendix II – Table* 6 (108).

Conservative therapy is therefore mostly used for symptomatic cases. It aims to prevent the need for surgery and also prevent future problems (82). In asymptomatic cases, there hasn't been any long-term improvements seen and there is a lack of longitudinal studies to provide evidence of the efficacy of the treatments, both surgical and conservative (78, 82, 92). A review of pediatric literature concluded that orthotics and heel stabilizers work for decreasing symptoms and increasing support in symptomatic FF cases, along with conservative methods and that also for severe cases, custom made orthoses are better used to eliminate the compensatory disorders that are present (82).

Out of those methods, a long-standing debate exists over the use of orthoses for treatment of FF, especially of the flexible type as there is no way to tell between the FF that will remain asymptomatic or become symptomatic (82). Orthotic treatment has been recommended previously for asymptomatic cases to balance out the support in FF and prevent future disability but there is still a question on its efficacy (48). In a prevalence study on preschool children, it was found that approximately 10% of the children were using orthoses despite that only 1-2% of them had pain (32). This points out the number of unnecessary treatments that are being prescribed to those children who don't require it. A critical review of current literature available investigated the use of pediatric foot orthoses and its efficacy (109). 13 studies had met the criteria but only 3 of them had a quality index score above 50%. This indicated the poor methodological quality that exists in most studies evaluating the efficacy of orthotic intervention in the pediatric FFF population and clinicians need to consider this lack when making decisions for the management of FF (109).

According to a good system of orthotic treatment, an orthosis should do the following: [1]Accomodate the structural deformities and protect the foot, [2]provide rigid support but also allow for natural foot shape change in movements, [3]correct the malalignment and [4]create an optimum patient-orthoses interface to prevent the breakdown of soft tissue (79). An ORT device for hyperpronation control called the dynamic stabilizing innersole system (DSIS) was developed in 1992 to control the arch flattening in 3 planes (sagittal, frontal and transversal) which gave it a very good advantage to the other systems. It has reported good outcome results for children between 2-16 years of age and is until now very frequently used (79).

In an attempt to alleviate the controversy regarding if children with FFF should or shouldn't be treated with arch supports, a gait evaluation of the immediate effect of orthotic treatment was measured in a study in Hong Kong (49). The sample population was small, of only 8 subjects (with the mean age of 6.3 years and an arch index of >3.0), that were referred to the orthotic unit with prescriptions for arch supports. The children were provided with custom made orthoses and then evaluated by a gait motion analysis system. A comparison with the shod was also done. There was a significant decrease of IR and a decrease in ABD of the forefoot in the orthotic group. The degree of eversion was also decreased, giving a decrease of total eversion by 39.5%, with the exception of heel strike (where there was no difference). The orthosis also decreased the delay in resupination. Overall, positive effects were seen on the subtalar motions and this may consequently decrease stress on foot structures and relieve pain. The Hong Kong population is generally known to have high laxity which can limit the significance of these results to other populations, also a 2D system was used for the motion analysis which may not have detected small changes. However this is the only study that examines the immediate effect of orthotic treatment (49). Other studies have also shown similar findings with a longer period of usage, but there were also results that showed the contrary. A prospective research that evaluated the influence of corrective shoes and inserts on FF showed interesting results. 129 children were recruited in the age range from 1-6 years old with FFF, and were randomly placed into 4 groups of different intervention. 1 group was a control, and the 3 others used a form of orthoses; corrective shoes, the Helfet heel cup, or a custom-molded insert (110). They were treated with their intervention for a minimum of 3 years but only 98 children completed the study. After the analysis of covariance between the groups, there were no significant results seen between the groups and the variables that were measured all improved over the 3 years but it was regardless of treatment or not. The relationship between laxity and improvement was analyzed as well, and the data showed the greatest improvements came from the children with greatest laxity (statistically only). A recommendation was made for increase of barefoot walking time or the wearing of soft shoes for the FF sufferers, but no treatment for children with typical FFF was advised, unless symptoms were severe (110).

A randomized control trial (RCT) with strong evidence evaluating orthotic treatment in children with FFF showed similar findings. The RCT used 2 types of othoses, but on an older age group of children between 7-11 years old (53). The orthoses were either [1]custom-made or [2]ready made. 160 children continued to the follow-up and were divided more or less equally into the 2 groups. Outcome measures used tested their gross motor function, pain (VAS), self-perception (by a questionnaire) and exercise efficiency (20m shuttle run). Measurements were taken at baseline and at 3 and 12 months, and in comparison, there were no statistical significant differences in the outcome measures. Some variables did change over time but in a similar manner in all the groups, but they were not clinically significant (53). The diagnostic measures used (calcaneal eversion and navicular drop) seemed to have a poor reliability in this trial, therefore their lack may have been a contributing reason for the poor results. The follow up was also for only 1 year which may not have been long enough as even the results for pain relief had no significant differences between the groups. In a comparative study, a group of children with FF underwent a rehabilitation program with a mean period of 2.75 years and were compared with a group of children who have been treated with insoles and special footwear (108). 300 children were recruited, with the mean age of 3.4, with bilateral FF over a period of 2 years. When the comparison was made, the percentage of success was fascinatingly higher for the children who underwent the therapeutic exercises and only 6.3% of them remained with FF post the rehabilitation, whereas 31.45% of the orthotics group remained flat-footed. The authors concluded no influence of the use of orthotics on the natural development (108).

Despite the results from those studies which show the non-significance of using orthotic treatment for children with FFF, there has been some where the opposite has occurred. In children with another associated condition such as a neuromuscular disorder or orthopedic pathology, where the FF is more symptomatic or vulnerable to becoming rigid, the use of orthotics seems to be promising. Twenty-five children with hypotonia were included in a comparative study between receiving gross motor therapy and orthotic treatment (106). Their ages were in the range from 18 months to 5 years and they also presented with hypermobility.

All the children were already receiving GM therapy twice per week for their motor delay previous to the study. They were randomly allocated into 2 groups, one receiving the GM therapy and orthoses, and one receiving the GM therapy alone. The group who received both treatments (n=13) had a significant change in their arch development after 6 months (reaching the age expected mean for the Arch Index) (106). This is probably because the joints and ligaments assumed the correct position over time which positively affected the stability and strength in combination with the exercises. No clear evidence was seen in gait but the GM therapy seemed to have a bigger effect on gait parameters overall (106). These results oppose those from other studies that investigated the effect of orthosis on arch development; however most of these have been done on normal developing children. There is room for future research to compare the effect of these types of interventions on healthy children with children that have underlying conditions such as hypotonia which is a common characteristic of Down’s syndrome. However this study was done using a very young age group (below 3 years of age) with immature gait, which makes it more difficult to analyze, and also had no control group due to ethical reasons (106).

2.3.3.2 Surgical treatment

Surgery is always the last resort option to treating FF cases. In severe cases, arch supports or short leg walking casts are attempted at first and surgical options are sought out only if they fail (82). In less severe cases, surgery is only sought out if conservative measures aren't successful. From mainly reports, case studies and expert opinions, it's been stated that rigid FF may benefit from surgery the most (111). Indications for surgery usually include pain, decrease in activity, tiredness, decrease/change in activities of daily living and an inability to walk (112), which mostly occur in rigid or severe symptomatic FF.

Surgical treatments, however, haven't shown strong evidence in long-term outcome studies and there is no universally accepted procedure (111). The procedures usually come under one of the following: [1]tendon transfers, [2]tendon lengthening, [3]osteotomies and [4]arthrodesis (last resort) (82).

Arthrodesis procedures have been common despite that they score poor outcomes in the long-term as it causes severe loss of ROM (111). Evan's osteotomy procedure normally retains motion and have been good in correcting heel valgosity and forefoot ABD, but as it doesn't place an effect on the medial column structures of the foot, combined techniques are often used to increase support of the MLA (such as tenosuspension). Evan's technique isn't recommended for children below 10 years (111). For the younger age groups, where the foot is still growing rapidly, it is more sufficient to use soft tissue procedures such as tendon lengthening, especially since the integrity of the MLA in WB depends on good intrinsic strength which is ligamentous and bony (113). For cases that can't be controlled by orthotics or conservative methods, osteotomy procedures have been used to diverge the loading on the feet from the medial plantar structures to a more neutral pattern. As this alone doesn't structurally change the MLA, combined techniques are used as well and they usually follow Hick's principle on the importance of the medial plantar fascia strength (113). The aim is to replace the disrupted fascia by the medial half of the calcaneal tendon. There's been a record of several case reports showing satisfactory results with this technique of children with severe FF deformity and excessive hypermobility (113).

2.3.4 Factors influencing FF development

There are many factors that have an effect on the development or maturation of the arch in its development period, predispose children to having FF, or increase/decrease the likelihood of having FF. Their importance is sometimes overlooked at in the management of FF. Knowledge and understanding of the many different factors influencing the feet can increase the insight into the cause of the deformities, why it is persisting and different injury mechanisms (94).

The factors that increase the risk of developing FF or ones that simply alter the development of the foot posture should be considered by all physicians' dealing with foot problems as treatment plans may depend on them (81). These factors include; ligament laxity, obesity, gender, age, related malalignments (e.g. rotational), shoe habits (81) and many more. There is still room for investigation on factors or causes that increase the likelihood of developing FF or on potential ones that could help prevent the overall deformity from continuing into adulthood which is the most major concern of parents (81). The most frequently cited factors in the available literature will be discussed in the forthcoming chapter including the influence of age, gender, associated conditions and area of living.

2.3.4.1 Age

In the majority of the studies on flat feet, age is mostly always concluded as a primary predictive factor. The youngest age groups always have the highest incidence of FF when compared to the older age groups in any given study, even when age is not the factor being investigated in the study.

A Congolese study that focused primarily on the relationship of FF and wearing shoes (29), showed that in the age groups of 3-12 year olds, the proportion of fallen arches decreased with age, therefore the highest proportion of FF was in the 3-4 year old group. A Taiwanese study that included 1598 children also showed that the highest prevalence in the youngest age group (3 year olds) which made up 54.5% of the sample population between 3-6 year olds, which is relatively large (31). Another Taiwanese study on prevalence that recruited a population of a higher age group (of 7-12 years old) classified 2083 feet using footprint analysis again concluded the same results with the highest prevalence of FF in the 7-8 year old group which were the youngest in that study (26). However, the methodological quality reliability can be questioned in the study as some variables weren't controlled. The mean prevalence of the population was 58.7% which is higher than most studies in older age groups. Many factors such as performance, physiological knock-knee, laxity and so on were evaluated on their relationship with FF in another Asian study from Southern Taiwan, where age was also included as an investigated factor (33). There were 377 children included, ages 2-6 (preschool period) and according to their results, 57% of the 2-3 year olds were classified with moderate to severe FF, 40% of the 3-4 year olds were classified with the same and only 21% of the 5-6 year olds were in the same degree of severity group (33). This shows a clear decrease of the FF proportion between the age groups, with the highest being again in the youngest group. There were also quite significant differences in the number between the ages, almost 20% less per 2 years of increasing age which may imply an important connection to the largest developmental phase of arch maturation in those years. To deviate from Asian populations, an Austrian study evaluated 835 children between 3-6 years old for cofactors' age, weight and gender effect on the FF diagnosis (32). The German ORT association classification was used here for classification. The prevalence decreased with age considerably, with 54% being in 3 year olds and 24% in 6 year olds. The range of valgosity angles was also lower in the 6 year olds. These values described the prevalence of FFF only as the prevalence for pathological FF was less than 1%. Age was concluded as a primary predictive factor in this study (32).

As continuously shown the prevalence of FF does decrease with increasing age. From the results being conclusive in majority of the studies done worldwide, it is unlikely that the race or ethnicity affects this factor; however they can affect the percentage of prevalence. Whether the research was using a population of children from Europe, Africa or Asia and so on, the results are nevertheless the same when it comes to seeing the effect of age on the FF incidence. Those results should not be surprising knowing the natural history of the arch maturation stages and that the younger age groups are in earlier developmental phases whereas the older age groups have spontaneously and gradually resolving FF. This proves the importance of knowing the age of onset and age of child in examination; if the age of the child is below 6 years of age it brings the question on whether to treat the children with FF in their preschool period or if the treatment wouldn't be effective or beneficial as it is a relatively normal finding.

2.3.4.2 Gender

It has been repeatedly reported that boys have a higher tendency for flat feet than girls. The reasons are still not fully understood however research proved that it is because of a generally slower development that occurs in boys in comparison with girls as mentioned previously on arch maturation (12).

A Taiwanese cohort with a 1 year follow-up on the change of FF in children mentions a strong gender difference noticed. At the study's follow-up, boys had the majority of FF than girls (25). An Australian population of 835 children aged 3-6 were evaluated along with cofactors such as age, weight and gender and according to them, boys also had a higher tendency to having FF (32). Similarly, the previously discussed Taiwanese and Congolese studies on the relationship of age, have also found results for a gender relation all resulting in boys having a lower MLA in comparison to the girls (26, 29, 31). One of them even displayed a large difference where the number of boys with FF was 2x more than the girls, regardless of the age (26). These results are consistent with many other works.

A Spanish study with the purpose of investigating overweight and obese children (of 9-16 years old) and their weight's influence on FF also resulted with boys showing lower MLA heights when compared with the girls, regardless of the weight (94). An investigation exploring the epidemiological factors that influence the height of the arch in an older age group of Polish children (7-15 years) showed results that were in agreement, even for a European population (12). It however compared the genders within different areas of living (urban or city), but also regardless of which area the children lived in, boys overall had a lower MLA height than girls (12).

The Polish investigation saw changes in arch height and growth even after 12 years of age, this shows that the gender comparison even at older ages still showed that development does in fact occur at a slower rate in boys than in girls. Also when comparing all the studies mentioned, boys do tend to have lower MLA heights regardless of other factors, which makes it an independent influence on FF.

2.3.4.3 Ligament laxity

The MLA integrity is relied upon the soft tissue structures supporting it such as the ligaments, tendons and also bony support, more than the muscles surrounding it. Since diagnosing FF uses the height of the MLA as its main reference, and that the MLA structure has the highest variability in the foot, a direct relation of ligament laxity and the height of the arch can be summed up (86, 94). FFF is said to be caused by, or be a part of a generalized manifestation of a ligament laxity (14, 30). Children with hypermobility and higher ligament laxity have weaker ligaments and therefore more unstable joints and for that it may even cause a delay in walking (106). Hypermobility in children is most often measured using Beighton's scale. The scale records the presence of hypermobility at the wrists, 5^{th} metacarpal phalangeal joints, the knees, elbows and LS spine (forward flexion) and it scores using a 9-point rating, where hypermobility is considered positive when the score is minimum 5/9 (99). A higher ligament laxity may be from an underlying condition, or just congenitally. In children with atypical development such as a developmental syndrome, the presence of FF is unlikely to decrease with maturity, as children with normal and healthy development (106).

There was a study done in Turkey on primary school children to examine some factors that are related to FFF (30). 519 children were included with a mean age of 9 years. Factors such as age and gender were analyzed as well as ligament laxity. In the severe and moderate FF group, the percentage of the children who were hypermobile was 27.6%, which was considerably larger than the non-hypermobile children with FFF, which was only 13.4% (30). Girls had a higher tendency to hypermobility and having FF in this study, which is contrary to previous gender-related studies mentioned earlier (30). A study made in Taiwan had a similar aim for investigation (31). A larger population sample of 1598 children was used and more factors such as obesity and W-sitting habit (first study to analyze this factor) were analyzed. 599/1598 children suffered from bilateral FF in this study, with the prevalence being the highest at 3 years of age (54.5%), and also with boys having a greater tendency to FF. As for the joint laxity results, 46.7% of the children with FF were hypermobile, which is a considerably large portion of the sample (31).

In India, an investigation on the influence of footwear on foot morphology also noted the influence of laxity (36). It consisted of an older age group of children (4-13 years old) and 2300 footprints were analyzed. After classifying the feet, only 154 revealed flatness which gives a low prevalence of 6.7% in this region. Ligament laxity was detected in 14.4% of the children with FF here (36). It is lower than Asian and some European populations too, because of the differences that exist in culture and genetic predispositions. In the South Taiwanese study that focused on illustrating the correlating factors of FFF with the highest clinical significance in preschool children (n = 377), the most common findings they recorded from the children under the moderate-severe FF group were; increased weight, increased ligament laxity and shorter height (33).

If laxity is in fact a factor not only affecting the development of MLA but affecting the prevalence directly also, then differences with race would show. Different races have different laxities; Asian children, as seen from the research, are more lax than Caucasians. In a prevalence study (Cheng et al), it was shown that in a population of Chinese children, 100% of the 3 year olds were lax, but this decreased with age (15). Also the Indian study mentioned showed a very low prevalence of both FF and hypermobility in general when compared with the results of the other studies. The 1 year follow-up cohort study that was done in Taiwan of children aged 3-5 also had included laxity (as measured by Beighton's score) as one of the significant factors evaluated (25). The prevalence of FF after 1 year decreased by 14%, however, 62.4% of the children who started with FF remained still with FF and a large portion of children in this group were joint laxity sufferers, along with kids that were younger and overweight (25). This may entail that children with joint laxity don't necessarily follow the physiological arch development as non-hypermobile kids do and that it may increase the likelihood of 'keeping' the FF deformity for long-term. An example of this was the Turkish research that determined the prevalence of FF in children of an older age group (mean age of 9 years) mentioned earlier in the chapter where a large difference was seen when comparing the percentage of children who were hypermobile with FF and the ones who were non-hypermobile with FF (difference of 14%) (78).

2.3.4.4 Overweight/Obesity

Many reports that evaluated a number of factors stated similar findings where obese or overweight children have a higher prevalence of FF than normal or underweighted children. There were no significant differences in cultures or where the studies were done, the results had always been in agreement. Obesity has weight related problems such as discomfort and pain in walking, malalignments of lower extremities but very frequently FF also (94). This is largely due to the fact that an increased weight equals to an increase on loading stresses on joints, specifically to the feet in stance, and from that grew the assumption that the weight of a growing child can largely influence the development of foot posture.

In a previous reference to a Taiwanese study on prevalence of FF, of the children that classified with FF, a large number of them were overweight, and the underweighted children had even lower odds than the normal weighted children to having FF (26). Children whom are overweight were also commonly found to be in the moderate-severe FF group in the other similar Taiwanese study which evaluated preschool children (33). The follow-up cohort study that was referenced several times already similarly revealed a higher chance of having FF and remaining with it if the child is overweight (25). In an Australian study, the results are also compliant, as out of the 835 children in preschool that were examined, the percentage of over-weighted ones with FF was 51% (32). Also, 62% of the obese children had FF, and only 42% of the normal weighted children had FF (32). This demonstrates a probability of having FF being 3x larger if the child is overweight/obese than normal weighted.

A unique German study that sought out to inspect the influence of body weight on foot development revealed five different foot profiles that existed in their population used (34). The profiles were created using a cluster analysis of all the variables measured from a 3D foot scanner. The age group was between 2-14 years of boys and girls (1450 and 1437 respectively). The foot profiles discovered were: 1)FF, 2)slender feet, 3)robust feet, 4)short feet and 5)long feet. The children with the highest BMI’s had robust feet profiles which consisted of average arch heights. Within the FF profile, the overweight children were the most frequent. The overweight children also had more short feet than the normal weighted. The children whom were underweight had a lower prevalence of FF at an older age than the rest of the sample. This brings about a question to whether if less mass leads to generally, a better development of the arch or not.

When looking the at the FF profile however, the BMI was only slightly increased and the differences weren't as expected therefore it became questionable to whether the FF in obese are from lower MLA's or from the presence of thicker fat pads (34). It has been suggested that the fat pad remains longer in obese children, imitating an adaptive response as protection against the excess stress that's created by the increase of body mass (26). An attempt to answer this was seen in a study that considered the fat pad of obese children, where an ultrasound device was used to measure its thicknesses of overweight and obese children and normal weighted children (controls) (100). There are no significant differences in the thickness of the fat pad between the groups. Their conclusion implies that the MLA is lower in children with a higher BMI because of the increased load that is placed on the foot and that they also have larger foot dimensions (i.e. 'Robust feet'). The study was however done using a small sample of only 19 obese/overweight children and 19 controls (average BMI), so the results may be different in a larger or more accurate sample. However the measures used were reliable with the use of a control group therefore it should be taken into consideration. In a related Spanish study, that was previously acknowledged, which assessed the MLA of children with obesity, the results revealed significant differences in the obese group (after a comparison with normal-weighted children) showing much lower MLA heights (94). The direct measurements came from the use of radiographs and the parameters displayed a high incidence of FF suggesting that changes in the footprints of the obese children are because of the changes in the osseous structure of the MLA and not the presence of the fat pad, as seen clearly on the X-rays (94).Those studies, therefore, in combination can provide a reliable conclusion that the flattening of the arches in obese and overweight children are from structural changes rather than from a thicker fat pad.

To examine the effect of weight on dynamic function of the foot, a study using dynamic variables was done. It employed 17 obese/overweight children with matched control subjects (101). The average age was 4.4 years. The main concern was that continued stresses, such as those that come from increase in weight, could cause structural changes in the foot, indirectly affecting the development. It is still unknown what the threshold is for causing potential tissue damage in the midfoot of growing children (101). The results revealed significant differences in the contact areas and peak pressures which were overall higher in the obese, specifically in the midfoot region. The most significant difference between the groups for the force-time and pressure-time integrals were only significant in the midfoot region and not the others, concluding the midfoot region being most affected.

Another interesting study from Germany on the topic of obesity in children had classified 3 different loading types on the feet and tested their effect on foot function and plantar pressure distribution (28). The 3 types of loading were divided to temporary, short or long-term loading. Plantar pressure variables were taken along with pressure force data. In static conditions the obese had increased mass on the soles of the feet but had it distributed over a large surface area therefore no significant affect on peak pressures were seen. However in dynamic loaded conditions, the peak pressures were much higher than in unloaded conditions and there were higher peak forces too, in the obese group. The long-term simulated mass influenced the contact area, having it highest under the forefoot (27). This brings a concern as this region is susceptible to injury as it is made up of smaller bones, and a long-term excess stress, like in obesity, on these joints can cause harm.

In contrary to the majority of these studies, there is a record of one from Australia which presented the opposite results and found a relationship between FF and weight that was inverse (meaning that heavy children showed less flat feet) (114). It had recruited 140 children from ages 7-10 years and used the FPI-6 as the diagnostic method. 31/140 children had FF and so the anthropometric values collected of foot dimensions were compared with the non-flat-footed. From the contradicting findings in this study, it may mean that a more standardized approach and larger sample is needed to verify its reliability or may be because of the different methods used for classifying obese/overweight children and classifying FF.

2.3.4.5 Footwear

A systematic review researched what is available in literature on shoes effect on gait (115). Their criterion was to compare children below 16 years old that go barefoot, with children whom are shoe wearers. The review's main conclusions showed that with shoe wearing, 8/9 motion variables measuring foot motion are decreased, and that the only motion variable that increases with footwear is subtalar rotation. There is also a decrease in muscle strength with the wearing of shoes, along with a decrease of intrinsic muscle activity. The motion of the hallux is also significantly decreased, which may be why there is a decrease of windlass mechanism occurring, which inadvertently decreases the raising of the MLA (115). Many studies have proved the relationship that exists with the wearing of shoes and an increase of likelihood to developing FF and it has been one of the main factors researched in pediatric foot care. The reasons may be due to, as above mentioned, the decrease of intrinsic foot muscle activity and decrease of proprioceptive information received by the foot in locomotion when wearing shoes, indirectly affecting the foot posture and arch development as the structures' support functions start to lack in strength.

A literature review showed the effect of being barefoot from a collection of studies from different populations such as the Philippines, Central Africa, Belgian Congo, natives of the Soloman islands and Chinese natives (116). All the results were consistent with the same findings showing that the unshod foot has excellent mobility and flexibility, thickening of the plantar skin and variability of the arch height with absence of static deformities. The review recommended that shoes for children should be based on the barefoot model.

In a Congolese study, 1851 children were recruited for research on the relationship of FF and wearing of shoes (29). This is in connection with the urban and rural areas as in the urban areas, shoe wearing is more common than in rural. The age range was from 3-12 years and the footprints were used for analysis. Results showed that the urban population in general had a higher proportion of FF. The most significant difference was in boys who wore shoes and those who didn't between the ages 5-12, with a higher MLA height being in the ones who didn't wear shoes (29). African children have a habit of walking barefoot, and this could be the reason for the increase of the MLA height in comparison with some European studies (29). The results correspond with other studies where FF was more common in children who wore shoes. In one, 2300 footprints of Indian children, aged 4-13, were investigated (36). 745 children never used shoes, where in some parts of India, this is common. There were only 154/2300 feet that were flat which equals to a low prevalence (6.7%), therefore generally the incidence in the population is low for FF, whether or not footwear is worn (or could be a result of the fact that they don't wear shoes from such a young age). 1555 children worse some sort of shoes, 1551/2300 had normal feet and 594 had high arched feet. However in the population who had FF, there was a significantly higher prevalence in children who wore shoes than the unshod (8.6% to 2.8% respectively) (36). There was also the highest concentration of FF in the 6 year olds who wore shoes, which may imply a critical age for arch development below 6 years of age.

When it comes to the type of footwear, this may also be significant, as it is said that closed shoes inhibit the development more than sandals and slippers and this may be due to the decrease of the use of intrinsic muscles in the feet in closed shoes, and that in sandals there is an increase in activity to keep the slippers from falling off (36). This is shown in another Indian study performed (117). A survey was used of 1846 persons over the age of 6 (mean age of 28.8 years). Only 54 of the subjects had FF (again a low prevalence of 2.9%). 30 of them had recalled their first shoe wearing before the age of 5. 17 of them had started between the ages 6-15 years and only 1.75% of them had started after the age 16 (117). Of those who had footwear before 6 years of age, the ones who used shoes for more than 8 hours per day had a much higher prevalence. This study shows interesting results with these relations (117). However because it had used a survey, being a recall of events, it could mean that exaggerated or incorrect information can occur but the subjects were blinded in the trial and for the majority of the time, the year they have started wearing shoes is an event that is not easily forgotten in their cultures.

2.3.4.6 Other factors

It has been questioned as to whether FF affects the physiological performance in children or even whether the physical activity and amount of it affects the development of the arch or not.

A study exploring the epidemiologic factors affecting arch height attempted in investigating this relation (12). 60 children were analyzed, aged 7-15 years and their physical activity was measured by a detailed questionnaire. 16 of the children with FF had high levels of physical activity, but 38 with FF had very low levels, therefore inactive children do have a higher prevalence. This has also been previously related in reports to obese children and how being inactive predisposes to FF from a decrease in muscle/strength and tone and consequently an increase in weight, but also that children who are obese or overweight participate less in physical activity in general and therefore also increase the likelihood of a slower or improper development. Another study that examined the effects of FF on muscular performance asked the children (n=377) of their study to perform 6 tasks: squat to stance, raising on heels as many times as possible, keeping a toe walk, walking on the heels, standing on one leg, and hopping on one leg. After comparison of the children with moderate-severe FF to the normal-mild FF group, the tasks' results showed obvious lower scores for the children who suffer from FF (33).

The epidemiological study also included the difference between those living in rural or urban areas (12). In the rural areas, the arch height increased with age by 80% in the active boys and 145.4% in active girls. For the same age groups but in the city population, there was still an increase for active boys and girls with age but it was much lower, being 33.5% and 96.8% increase respectively. In urban children, arch height was 26% lower than in rural areas (12). These results may be because of the reason that in rural areas, children may be more active than in the city areas and also that they are more often unshod in rural areas in comparison with urban areas. According to another study on the prevalence of FF, a relationship between FF and the social level of the children's families was found (35). There was a significant decrease in prevalence of FF in the lower and lower middle class families. This may suggest a strong connection with these classes related to them being more active, or perhaps less able to provide shoes at a very young age so remain unshod for longer. One study researched the effect of nutritional status on prevalence of FF in school aged children (n= 500, 6-12 years) living in urban and rural areas (118). After the data was collected and the classification was done, there appeared to be a significant prevalence of FF between rural and urban living children being 18.2% and 32.9% respectively. The nutritional status of the urban children was also higher (118). BMI in this study was a primary predictive factor, including age too.

FF is also often associated with postural knock knees (PKK) (111). The investigation on factors influencing FF in preschool children also presented in their results that children with PKK had a higher tendency to FF because of the position of the knee indirectly placing the ankles to a more valgus position (33). However this relation may also be vice versa as the pronation of the foot realigns the counter ground reaction forces at the calcaneus and by this, cause the developmental knock knee position (111). In the influencing factors study, 61% of the FF group had PKK, which shows the strong connection of the knee position to the feet, never minding which one of them is the actual cause (33). However it is important to note that the presence of PKK will more likely mean a presence of FF deformity.

It’s also been reported that habitual sitting or sleeping positions of children can affect the lower limbs and cause deformities (21). The frog leg position can cause an ER deformity in the hips and tibia which can lead to pronation of the feet. Similarly, the W-sitting (hips in IR with knees in ER) position too can affect the position of the feet through increase of femoral anteversion (21). There’s one apparent study that sought to evaluate the influence W-sitting habit, amongst other things such as age and gender, on the development of flat feet in children aged 3-6 years. The results showed that out of the 1598 children included in the study, only 17.3% had a habit of sitting in the W-position but that the highest proportion of them were in the group diagnosed with bilateral FF. The result was also significant in the group diagnosed with unilateral FF. The conclusion was that it is probably influential in this way because of the extreme valgus position it places the foot in, along with abnormal ER of the tibia and IR of the hip (31). An abnormal ER position of the tibia has been shown to be related to the nature of FF.

Some other known factors are of related disorders that can predispose children to FF, and not only those who are obviously pathological such as a rigid ORT deformity but those that affect the entire musculoskeletal and motor development in general such as spasticity in cerebral palsy or hypotonia (acquired or congenital) which additionally cause a motor developmental delay. Hypotonia is very often associated with FF, and is detected earlier than foot posture becoming relevant (85).

There are many factors that influence the arch development in a growing child. On these issues that can affect the development of FF, it is most useful to look at the factors that could respond to an external effect and be easily changed to influence the development positively. These include factors such as obesity, shoe modifications or shoe wearing, influencing the weight and muscle strength and factors that are not as easily altered or impossible are those such as ligament laxity, genetics and gender (85).

3 Discussion

Physiological pediatric flat foot presents with the high amount of variability, and is seen to cause alterations in gait and either spontaneously resolve or continue into adolescence. The prevalence estimate of having FF for preschool children is around 45% and 15% in children with the mean age of 10. Despite the amount of research, because of the lack of a universal criterion for classification or defining flat feet, especially in children, it is still difficult to draw conclusions of what is considered 'normal' development. Another area that makes this deformity's evaluation complex is its multi-factorial etiology. Flat foot is more of a presentation of a deformity that belongs to a broader clinical unit because it has many factors contributing to it.

Regarding the foot in growth and development of children, many studies exist on the differences of foot posture and gait between different age groups of growing children in order to gain normative values to aid with identifying abnormal from normal development. The variations and ranges of these changes and when they occur have shown to be clinically important when treating children, as it supports the knowledge of when to apply treatment or when not to, and to also distinguish abnormal from normal developmental variations. For example, in younger children, gait deviations are a consequence of the typical torsional variations that are a part of the process of maturation. Foot deviations like flat foot are also a consequence for the same reason. With that in mind, their clinical significance therefore is questionable as they are known to neutralize their positions with age. It is therefore important to know the whole spectrum of the lower extremity changes and their order to make a concise evaluation and therapy plan if necessary because problems in gait in the long-term can lead to LE pathologies later on in life and if a suspected deviation seems to be persisting longer than 'normal' then an intervention is more likely to succeed if it is applied early.

FF in a healthy developing child corresponds to lack of muscle strength, CNS maturity, growth of foot structures and ligament tightness. It is usually a physiological flexible foot type that corrects itself with age. If optimal developmental conditions of all these factors aren't met, especially in the critical developmental age, it is more likely to progress rather than resolve. The primary and most rapid age of arch development is between 4-5 years of age in accordance with an increase of postural control, more availability of muscle activation patterns, resorption of the fat pads under the medial soles and fusion of the secondary ossification centers in the feet. More mature gait patterns also emerge around this age correlated with walking experience. A second, but slower period of critical age for arch development is seen between 5-6 years of age. After 6 years, the development continues but remains on a plateau.

The arch maturation doesn't depend only on the maturity of the musculoskeletal system, but appears to be due to the interaction of all the systems that affect the foot complex and allows it to maintain the arch through some compensatory mechanisms. Foot abnormalities are often blamed for a delay in motor development however children with a healthy maturation profile with deformities still perform well in gait and activities. If the vice versa would occur, as in having a disorder that delays CNS maturity or affects the rate of growth or muscle control, a delay in the arch maturation is likely to occur and categorized as non-physiological. Correcting the foot here will only help functionally and not correct the motor delay as the foot posture development in this case is the reflection of the integrity of the CNS and cannot directly affect it.

The foot arches begin to develop at the onset of walking, when there are applied loading changes over the feet. The arch volume has even been seen to increase in volume with increasing of age, especially in the first 2 years of walking experience. This developmental initiation is due to the effect of mechanical forces within the foot that are needed in order for the foot bones and structures to adapt and change to resist them. This is an example where function plays a major role in changing structure. However, if the loading is not within a biological range, (from activity, weight of the child and other factors), duration and direction of the force may negatively affect the growth. This proves a strong relation between the incomplete ossification that exists in a developing child, and the presence of flat feet. As the bones provide the base of which the passive support attaches to, when they are still developing the foot remains mobile and the ligaments lax therefore the vulnerability of the foot in this age to deformity and injury is relatively high.

Regarding the implications of foot in posture and gait, many studies exist on investigating the relationship between the two. For optimal function of the LE, normal alignment and biomechanics of the foot arch is necessary. All the functions of gait such as the need for the adaptation of the feet to different terrains, propulsion of the body forward in movement and support of the body weight, require the support and function of the medial longitudinal arch. This raises the importance of the flat foot being more functionally important, than statically and that it always should be defined in those terms.

The height of the MLA is supported by passive and active components. The passive components consist of the ligaments, fascia, and tendons that play a role in elevation of the arch. The active components are the muscles that support the arch, especially in dynamic conditions. The tibialis posterior has been revealed as the most significant muscle involved in the elevation of the arch even when the passive structures are compromised. A dysfunction in the muscle has also been related to acquiring flat feet in adulthood. Inverter muscles in flat feet are found to be much higher in activity than in normal arched feet, resulting in weakness and lower activation from the lateral compartment muscles (the everters, such as peroneus longus). The increase of activity in the inverters may be explained by the fact that compromised passive structures of the feet require their actions to support the body weight in movement, or that the muscle are placed in compromised position of higher stresses from the flat feet. The precise reason for which causes which is not known, but many links regarding the feet have the same controversial relationship because of the foot being the lowest part of the kinetic chain where it can be influenced from the above proximal areas, or vice versa.

The majority of the studies found on the differences that lie between the flat footed or normal arched evaluated kinematic parameters alone. Moreover, the majority of these studies are on the adult population. Further studies investigating both kinetic and kinematic parameters are required as the role of the muscles and their effects should be made more known on how it influences the LE extremities as a whole. Different arch heights use the muscles differently and cause different tensions and change in the biomechanics of the lower extremity. Many of the symptoms that arise from flat feet relate to the imbalance of muscles which lead to malalignments in posture and the cause of injury or pain, especially in adults where overuse and fatigue symptoms prevail. Future studies, of longitudinal designs, with interventions directed at muscles that support the arch and their effects on treating or preventing flat feet could be an area worthwhile focusing on.

The presence of flat feet does in fact alter the lower extremity biomechanics and gait in children, whether it is asymptomatic or not, it is a structural change that has a high influence on the function and dynamics of the LE. The effect of flat foot on calcaneal and forefoot movements are the most clearly noticed. Many studies also displayed common kinematic differences between children with or without FF such as; walking at a slower pace, less stability, increase of plantar pressures in forefoot and midfoot and the effect is has on proximal limbs such as tibial IR, knee valgosity and hip F however temporo-spatial parameters are usually quite similar in both populations. Because of the proximal limb changes that flat feet have the capacity to cause, there is a connection of the deformity to LE pathologies, injuries, and low back pain later on in life. There are an increasing number of studies looking into this connection but they mainly include adult populations and also present the outcome after immediate or short-term intervention. Long-term outcomes would provide more accurate and beneficial information revolving around this topic and also the use of patients whom are symptomatic instead of healthy or asymptomatic individuals would allow a greater insight into the adaptation strategies and compensations of gait and posture that flat footed individuals use to cope with their difficulties in comparison with the asymptomatic. There is also a lack of these types of studies in the FFF children population.

Regarding the treatment of flat feet in children, a good base of evidence stems from a number of systematic reviews, CPG's, RCT's and expert opinions. A controversy still exists however on when to treat flat feet, whether it is necessary or not, and how. There has been very little evidence on the use of conservative treatment and modifications of the contributing factors and instead the majority has focused on the use of orthotics. Poor methodological qualities were noted from the studies that challenged the use of orthoses versus the use of a rehabilitative program and the shortness of long-term follow-ups produced a lack of knowledge on what treatments are actually effective or not. There has been, on the other hand, a good record of outcomes related to the use of orthotics in individuals with rigid FF. There is also not enough strong evidence on long-term outcomes of surgical treatment because of lack of longitudinal studies but as a general rule, surgical intervention is always the last resort of treatment after conservative has failed, and should be limited to symptomatic rigid FF.

The factors that are known to be contributing to FF should all be questioned in diagnosing and treating children with FF, as they have the power to provide very important information regarding the status of FF, its severity, and its possible outcome in the future. There's no shortness in studies that have established and discovered the most significant correlating factors in regards to foot development in children and those range from epidemiological factors to intrinsic factors. However, there aren't many studies to name on their continued influences and their impacts on persistence of flat foot after the development.

Age is a primary predictive factor of flat foot as the younger children always have the highest prevalence which is a mere reflection of the ascending maturation. However, this is true for the developmental period but there have been records of the incidence of flat feet increasing after the age of 10 again and then fluctuating, in healthy developing children. This shows that the development of the foot region is still an ongoing process in these older children and that they are still being influenced by external or internal factors that could have been addressed at an earlier stage but instead possibly overlooked at from the known expectation of that FFF spontaneous resolves of with age.

Another factor that has been noted as independent to the presence of flat foot is ligament laxity which may be congenital or acquired. All the studies that have evaluated hypermobility in children, and the rate of FFF have concluded strong correlation. Laxity is a factor that affects prevalence also as differences exist with the ethnicity and race of the population. It is also worth mentioning that even though studies have presented boys to having a higher tendency towards flat feet and a slower rate of development in gender, females have been presented to more likely suffering from hypermobility and being prone to injury than boys.

Many reports have also concluded that a high BMI correlates with FF. It comes to no surprise that being overweight or obese leads to more flattening of the arch than average weighted children. There are higher abnormal stresses and loads on the feet from increased weight that cause structural changes in the feet over-time and these include flattening of the arch from over-stretching or intrinsic damage. The foot during the growth period is very susceptible to deformity and injury therefore the highest risk of developing permanent flat foot from the abnormal stresses of obesity is possibly below the age of 5 when the joints of the foot are still undergoing fusion.

From the literature reviewed, there appears to be a striking importance of footwear on the development of FF. Motions in the foot are limited with shoe wearing and this indirectly results in a decrease of intrinsic muscle strength activity and decrease of the windlass mechanism in effect because of limited toe movements. There is a clear increase of likelihood in developing FF from early shoe-wearing because of these reasons. The greater part of the studies investigating the links of FF to urban or rural living always repeats that the rate of FF is much higher in the urban where shoe wearing is common, along with decreased levels of physical activity and external stimulation. The unshod population show very low incidences of FF, especially in African populations. Also, the studies that have compared children living in urban and rural areas show a decrease of FF presence in the rural areas within the same age group comparisons as well. This proves that perhaps the development rate of the foot is higher in the unshod and rural populations because of the stimulation it receives from the ground and the increase of strength of the muscles. Further studies on different types of footwear comparisons need to be addressed to expand the knowledge on the best footwear to be used for growing children but it is until now recommended for children's footwear to be based on the barefoot model. Whether the studies were examining the wearing of shoes or not, urban living children in general had a higher FF proportion than in rural living children which confirms the influence of other factors playing a role in the development of the arch.

Physical activity may explain partially for these differences. Children who have high levels of physical activity have been seen to have higher arches than those with low physical activity levels. Inactive children do have a higher prevalence in FF but this relationship may be bi-directional as the presence of FF has lead outcomes of poor performance in activities in comparison with the normal arched. This can be explained by the decrease of muscle strength and tone in the inactive children that leads to FF, or the decrease of strength because of the deformity consequently resulting in decreased activity. The primary conclusion is that participation in sport and activities for the increase of muscle mass, strength and stability should be encouraged from a very early age especially in the preschool children where they become more engaged in play.

What can be concluded from above is that there is no independent factor contributing to FF development as there are always more than one involved, or in relation with another. All the above mentioned factors may influence the foot development in the growth period of a child, therefore it is important to know how they may influence it and if they could be altered or not, to maximize the effectiveness of the management of FF in children, especially because both extrinsic and intrinsic factors will always influence the foot posture even after the age of arch maturity and will play main roles in persisting flat feet.

4 Conclusion

Many studies exist on the differences of foot posture and gait between different age groups of growing children and adolescents in order to gain normative values to aid with diagnosing abnormal from normal foot types. Those attempt to aid in management of the flatfoot and making clinical decisions. There is a lack of strong evidence for the long-term outcomes for treatment and management of FFF, surgically or conservatively and further longitudinal studies are needed. The majority of the studies that exist on the link of foot posture and the lower extremities are related to adult populations and there is room for further studies in the pediatric populations. Many studies found identified and correlated factors that are significant to flat feet development. However more studies are required on the differences between symptomatic and asymptomatic populations with regard to these factors. There was no sufficient evidence and lack of literature on the persistence of flat foot from preadolescence including its prevalence, contributing factors and theoretical concepts behind it.

Adult flat feet appear to be more from musculoskeletal origins than any other. Most symptoms that arise are fatigue, overload and/or overuse of the muscles and the presence of muscular imbalances. They also have an increased risk in their deformity becoming severe and disabling if not corrected. The majority of adult FF are residues of the pediatric FF condition that progressed into adolescence. This proves that there is room for increasing knowledge in the management of FFF to prevent the ‘keeping’ of the deformity in future, rather than focusing on treating or curing it only when necessary, i.e. when symptomatic.

The incidence of FF in children after the age 10, which is after the ‘developmental period’ has ceased, remains surprisingly high. Research also shows that some of these populations demonstrate large functional limitations and presence of symptoms which increase the risk of the deformities continuing into adulthood and becoming more severe. Only a few studies, to date, have been cited regarding that and there is a vast lack in analyzing children between the ages 10-15 on this matter. Comparisons in most studies are usually made between the normal arched children and the flat-footed, or made on the basis of examining only flat-footed children and concluding outcomes of specific tests and their similarities. I believe that further studies including those age groups, however with comparisons made between an asymptomatic group and a symptomatic, with a correlation of all the possible factors that may influence the foot posture such as their developmental profiles, height, weight, age, gender, footwear and so on, would provide much more beneficial results in understanding the persistence of flatfoot and also provide a basis of treatment strategies that could involve modifications of these factors. They would also provide useful for the younger children in the critical ages of development, where optimal conditions are most preferred, in the prevention of symptomatic flat feet. With the knowledge and modifications of some factors such as the weight, activity level, footwear, bare footedness, muscle strength and even habitual positions, maintenance of a physiological arch and prevention of future disabilities could be applied without the need of special interventions. The knowledge of the intrinsic factors that are more difficult or impossible to alter such as family history, hypermobility and gender also provide useful knowledge as to what to expect when managing FF, for example hypermobile children are more likely to remain with FF when they are older than children who are not hypermobile, therefore special attention should be given to those diagnosed with hypermobility from an early age.

5 Works Cited

1. *Prenatal and postnatal growth and development of the foot and ankle.* **DB., Bernhardt.** 12, Boston : Phys Ther., 1988, Vol. 68, pp. 1831-9.

2. *Infant and child motor development.* **Edwards SL, Sarwark JF.** Chicago : Clin Orthop Relat Res., 2005, Vol. 434, pp. 33-39.

3. **DR, Patel.** Basic Concepts of Developmental Diagnosis. *Neurodevelopmental Disabilities.* Netherlands : Springer, 2011.

4. *Primitive reflexes. Their contribution to the early detection of cerebral palsy.* **PA, Blasco.** 7, Minnesota : Clin Pediatr (Phila)., 1994, Vol. 33, pp. 388-97. 0009-9228.

5. *The development of mature gait.* **Sutherland DH, Olshen R, Cooper L, Woo SL.** 3, San Diego : J Bone Joint Surg Am., 1980, Vol. 62, pp. 336-53.

6. *Preliminary normative values for foot loading parameters of the developing child.* **Bosch K, Gerss J, Rosenbaum D.** 2, Muenster : Gait & Posture, 2007, Vol. 26, pp. 238-47.

7. *Evaluation of early walking patterns from plantar pressure distribution measurements. First year results of 42 children.* **Bertsch C, Unger H, Winkelmann W, Rosenbaum D.** 3, Muenster : Gait & Posture, 2004, Vol. 19, pp. 235-42.

8. **Dalley, A.F., Moore, K.L.** *Clinically Oriented Anatomy.* Philadelphia : Lippincott Williams & Wilkins, 2004. p. 640. 0781759366.

9. **Nordin M, Frankel VH.** *Basic Biomechanics of the Musculoskeletal System.* 3rd. New York : Lippincott Williams & Wilkins, 2001. 0683302477.

10. **Lippert, L.S.** *Clinical Kinesiology and Anatomy.* Philadelphia : H.A Davis Company, 2011. pp. 267-278. 0-8036-2363-1.

11. **Gray, H.** *Anatomy of the human body.* Philadelphia : Lea & Febiger, 1918. 1-58734-102-6.

12. *Epidemiologic factors affecting plantar arch development in children with flat feet.* **Pauk J, Ezerskiy V, Raso JV, Rogalski M.** 2, Bialystok : J Am Podiatr Med Assoc., 2012, Vol. 102, pp. 114-121. 1930-8264.

13. *Measurements of foot arch in standing, level walking, vertical jump and sprint start.* **Chang Y, Hung W, Wu H, Chiu Y, Hsu H.** 2, Taichung : Int Journal of Sport and Exercise Science, 2010, Vol. 2, pp. 31-38. 2074-9775.

14. *Flat foot in children.* **Zoran V, Zorica Z, Cedomir V.** 5-6, Belgrade : Srpski arhiv za celokupno lekarstvo, 2009, Vol. 137, pp. 320-322.

15. *A cross-sectional study on the development of foot arch function of 2715 Chinese children.* **Leung AK, Cheng JC, Mak AF.** 3, Hong Kong : Prosthet Orthot Int., 2005, Vol. 29, pp. 241-253.

16. *Changes in foot-function parameters during the first 5 months after the onset of independent walking: a longitudinal follow-up study.* **Hallemans A, De Clercq D, Van Dongen S, Aerts P.** 2, Antwerp : Gait & Posture, 2006, Vol. 23, pp. 142-148.

17. *What is the best method for child longitudinal plantar arch assessment and when does arch maturation occur?* **Onodera AN, Sacco IC, Morioka EH, Souza PS, de Sá MR, Amadio AC.** 3, Sao Paulo : Foot (Edinb.), 2008, Vol. 18, pp. 142-149.

18. *Torsional variations in the lower extremities of normal children.* **RP, Stanton.** 5, s.l. : Del Med J, 1993, Vol. 65, pp. 313-6.

19. *Static, axial, and rotational deformities of the lower extremities in children.* **G., Fabry.** 5, Leuven : Eur J Pediatr, 2010, Vol. 169.

20. *Lower extremity rotational problems in children. Normal values to guide management.* **Staheli LT, Corbett M, Wyss C, King H.** Seattle : J. Bone Joint Surg. Am., 1985, Vol. 67, pp. 39-47. 1535-1386.

21. *Lower extremity abnormalities in children.* **Sass P, Hassan G.** 3, New York : Am Fam Physician, 2003, Vol. 68, pp. 461-8.

22. *Developmental biomechanics. Effect of forces on the growth, development, and maintenance of the human body.* **LeVeau BF, Bernhardt DB.** 12, 1874-82 : Phys Ther., 1984, Vol. 64.

23. *Lower-extremity rotational problems in children. Normal values to guide management.* **Staheli LT, Corbett M, Wyss C, King H.** 1, Seattle : J Bone Joint Surg Am., 1985, Vol. 67, pp. 39-47.

24. *Development of healthy children's feet--nine-year results of a longitudinal investigation of plantar loading patterns.* **Bosch K, Gerss J, Rosenbaum D.** 4, Muenster : Gait & Posture, 2010, Vol. 32, pp. 564-71.

25. *Change in flatfoot of preschool-aged children: a 1-year follow up study.* **Chen KC, Tung LC, Yeh CJ, Yang JF, Kuo JF, Wang CH.** 2, Taichung : Eur J Pediatr, 2013, Vol. 172, pp. 255-260. 1432-1076.

26. *Prevalence of flexible flatfoot in Taiwanese school-aged children in relation to obesity, gender, and age.* **Chang JH, Wang SH, Kuo CL, Shen HC, Hong YW, Lin LC.** 4, Taipei : Eur J Pediatr, 2010, Vol. 169, pp. 447-52. 1432-1076.

27. *The evolution of foot morphology in children between 6 and 17 years of age: a cross-sectional study based on footprints in a Mediterranean population.* **Stavlas P, Grivas TB, Michas C, Vasiliadis E, Polyzois V.** 6, Aarhus : J Foot Ankle Surg., 2005, Vol. 44, pp. 424-8.

28. *Does obesity influence foot structure and plantar pressure patterns in prepubescent children?* **Dowling AM, Steele JR, Baur LA.** 6, NSW : Int J Obes Relat Metab Disord., 2001, Vol. 25, pp. 845-52. 0307-0565/01.

29. *The development in footprint morphology in 1851 Congolese children from urban and rural areas, and the relationship between this and wearing shoes.* **Echarri JJ, Forriol F.** 2, Congo : J Pediatr Orthop B., 2003, Vol. 12, pp. 141-146. 1060-152X.

30. *Flexible flatfoot and related factors in primary school children: a report of a screening study.* **El O, Akcali O, Kosay C, Kaner B, Arslan Y, Sagol E, Soylev S, Iyidogan D, Cinar N, Peker O.** 11, Izmir : Rheumatol Int., 2006, Vol. 26, pp. 1050-3. 1437-160X.

31. *Relevant factors influencing flatfoot in preschool-aged children.* **Chen KC, Yeh CJ, Tung LC, Yang JF, Yang SF, Wang CH.** 7, Taichung : Eur J Pediatr., 2011, Vol. 170, pp. 931-936. 1432-1076.

32. *Prevalence of flat foot in preschool-aged children.* **Pfeiffer M, Kotz R, Ledl T, Hauser G, Sluga M.** 2, Vienna : Pediatrics, 2006, Vol. 118, pp. 634-9.

33. *Correlating factors and clinical significance of flexible flatfoot in preschool children.* **Lin CJ, Lai KA, Kuan TS, Chou YL.** 3, Tainan : J Pediatr Orthop., 2001, Vol. 21, pp. 378-82. 0271-6798.

34. *Foot morphology of normal, underweight and overweight children.* **Mauch M, Grau S, Krauss I, Maiwald C, Horstmann T.** 7, Tuebingen : Int J Obes (Lond)., 2008, Vol. 32, pp. 1068-75.

35. *Flexible flat feet in children: a real problem?* **Rodríguez AG, Jiménez FM, Varo MC, Gracia EG, Aracena JG, Crehuet JF.** 6, Malaga : Pediatrics, 1999, Vol. 103, p. 84.

36. *The influence of footwear on the prevalence of flat foot. A survey of 2300 children.* **Rao UB, Joseph B.** 4, Manipal : J Bone Joint Surg Br., 1992, Vol. 74, pp. 525-527. 0301-620X/92/4421.

37. *Three-dimensional measurement of foot arch in preschool children.* **Chang HW, Lin CJ, Kuo LC, Tsai MJ, Chieh HF, Su FC.** 1, Tainan : Biomed Eng Online, 2012, Vol. 11.

38. *Pressure distribution patterns under the feet of new walkers: the first two months of independent walking.* **Hallemans A, D'Août K, De Clercq D, Aerts P.** 5, Antwerp : Foot Ankle Int., 2003, Vol. 24, pp. 444-53.

39. *Posture control development in children aged 2-7 years old, based on the changes of repeatability of the stability indices.* **Sobera M, Siedlecka B, Syczewska M.** 1, Wroclaw : Neurosci Lett., 2011, Vol. 491, pp. 13-17. 1872-7972.

40. *Planovalgus and cavovarus deformity of the hind foot.* **K, KLAUE.** Heidelberg : J Bone Joint Surg, 1997, Vols. 79-B, pp. 892-5. 1535-1386.

41. *Evaluation of early walking patterns from plantar pressure distribution measurements. First year results of 42 children.* **Bertsch C, Unger H, Winkelmann W, Rosenbaum D.** 3, Muenster : Gait & Posture, 2004, Vol. 19, pp. 235-42.

42. *Clinical hindfoot measurement: a critical review of the literature.* **HB, Menz.** 2, Victoria : The Foot, 1995, Vol. 5, pp. 57-64. 0958-2592.

43. *Extensor deficiency: first cause of childhood flexible flat foot.* **Vittore D, Patella V, Petrera M, Caizzi G, Ranieri M, Putignano P, Spinarelli A.** 1, Bari : Orthopedics, 2009, Vol. 32, p. 28. 1938-2367.

44. *Dynamic effect of the tibialis posterior muscle on the arch of the foot during cyclic axial loading.* **Kamiya T, Uchiyama E, Watanabe K, Suzuki D, Fujimiya M, Yamashita T.** 9, Sapporo : Clin Biomech (Bristol, Avon)., 2012, Vol. 27, pp. 962-6.

45. *Influence of the abductor hallucis muscle on the medial arch of the foot: a kinematic and anatomical cadaver study.* **YS, Wong.** 5, Singapore : Foot Ankle Int., 2007, Vol. 28, pp. 617-20. 1944-7876.

46. **Neumann, D.A.** *Kinesiology of the Muscular System: Foundation for physical rehabilitation.* 2nd. Wisconsin : Mosby/Elsevier, 2010. pp. 477-521. 978-0-323-03989-5.

47. *Dynamic biomechanics of the normal foot and ankle during walking and running.* **Rodgers, M.M.** 12, Ohio : Phys Ther Journal, 1988, Vol. 68. PMID: 3057519.

48. *Pes Cavus and Pes Planus: Anaylses and Treatment.* **Franco, A.H.** 5, Philadelphia : Phys Ther Journal, 1987, Vol. 67. PMID: 3575426 .

49. *Biomedical gait evaluation of the immediate effect of orthotic treatment for flexible flat foot.* **Leung AK, Mak AF, Evans JH.** 1, Kowloon : Prosthet Orthot Int., 1998, Vol. 22, pp. 25-34. 0309-3646.

50. *The effect of arch height on kinematic coupling during walking.* **Wilken J, Rao S, Saltzman C, Yack HJ.** 3, Houston : Clin Biomech (Bristol, Avon)., 2011, Vol. 26, pp. 318-23. 1879-1271.

51. *Toe walking, flat feet and bow legs, in-toeing and out-toeing.* **B, Jacobs.** 5, UK : Ped and Child Health, 2010, Vol. 20, pp. 221-224. 1751-7222.

52. *Problem feet in children.* **Fixsen JA, MChir FRCS.** Devon : JR Soc Med, 1998, Vol. 91, pp. 18-22. 1758-1095.

53. *A randomized controlled trial of two types of in-shoe orthoses in children with flexible excess pronation of the feet.* **Whitford D, Esterman A.** 6, South Australia : Foot Ankle Int., 2007, Vol. 28, pp. 715-23. 1071-1007.

54. *A comparison of kinetic gait parameters for 3-13 year olds.* **Chester VL, Tingley M, Biden EN.** 7, Brunswick : Clin Biomech., 2006, Vol. 21, pp. 726-32. 1879-1271.

55. *Static and dynamic foot characteristics in children aged 1-13 years: a cross-sectional study.* **Müller S, Carlsohn A, Müller J, Baur H, Mayer F.** 3, Potsdam : Gait Posture., 2012, Vol. 35, pp. 389-94.

56. *Early changes in muscle activation patterns of toddlers during walking.* **Chang CL, Kubo M, Buzzi U, Ulrich B.** 2, Michigan : Infant Behav Dev., 2006, Vol. 29, pp. 175-88. 1934-8800.

57. *Lower extremity kinematics in children with and without flexible flatfoot: a comparative study.* **Shih YF, Chen CY, Chen WY, Lin HC.** 13, Taipei : BMC Musculoskelet Disord., 2012, Vol. 2, p. 31. 1471-2474.

58. *The effects of low arched feet on lower limb gait kinematics in children.* **Twomey DM, McIntosh AS.** 2, NSW : Foot (Edinb)., 2012, Vol. 22, pp. 60-5. 1532-2963.

59. *Kinematic differences between normal and low arched feet in children using the Heidelberg foot measurement method.* **Twomey D, McIntosh AS, Simon J, Lowe K, Wolf SI.** 1, NSW : Gait Posture, 2010, Vol. 32, pp. 1-5. 1879-2219.

60. *Natural gaits of the non-pathological flat foot and high-arched foot.* **Fan Y, Fan Y, Li Z, Lv C, Luo D.** 6, Guangzhou : Plos One., 2011, Vol. 18, p. 3. 1932-6203 .

61. *Diagnosis of flexible flatfoot in children: a systematic clinical approach.* **Benedetti MG, Ceccarelli F, Berti L, Luciani D, Catani F, Boschi M, Giannini S.** 2, Bologna : Orthopedics, 2011, Vol. 34, p. 94.

62. *Relationships between clinical measures of static foot posture and plantar pressure during static standing and walking.* **Jonely H, Brismée JM, Sizer PS Jr, James CR.** 8, Washington : Clin Biomech (Bristol, Avon)., 2011, Vol. 26, pp. 873-9. 1879-1271.

63. *Lower extremity kinematic and kiinetic differences in runners with high and low arches.* **Williams DS, McClay IS, Hamill J, Buchanan TS.** 2, Delaware : J Appl Biomech., 2001, Vol. 17, pp. 153-63. 1065-8483.

64. *Relationship between gait biomechanics and inversion sprains: a prospective study of risk factors.* 34, Gent : Gait Posture, 2005, Vol. 21.

65. *Effects of arch height of the foot on ground reaction forces in running.* **Nachbauer W, Nigg BM.** 11, Alberta : Med Sci Sports Exerc., 1992, Vol. 24, pp. 1264-9. 0195-9131.

66. *Diagnosis and treatment of adult flatfoot.* **Lee MS, Vanore JV, Thomas JL, Catanzariti AR, Kogler G, Kravitz SR, Miller SJ, Gassen SC.** 2, IA : J Foot Ankle Surg., 2005, Vol. 44, pp. 78-113. 1067-2516.

67. *The relationship between foot motion and lumbopelvic–hip function: A review of the literature.* **Barwick A, Smith J, Chuter V.** 3, NSW : Foot (Edinb)., 2012, Vol. 23, pp. 224-31. 1532-2963 .

68. *The relationship between foot posture and lower limb kinematics during walking: A systematic review.* **Buldt AK, Murley GS, Butterworth P, Levinger P, Menz HB, Landorf KB.** 3, Bundoora : Gait Posture, 2013, Vol. 38, pp. 363-72. 1879-2219.

69. *Foot posture influences the electromyographic activity of selected lower limb muscles during gait.* **Murley GS, Menz HB, Landorf KB.** 2, Bundoora : J Foot Ankle Res., 2009, Vol. 26, p. 35. 1757-1146.

70. *Effects of calcaneal eversion on three-dimensional kinematics of the hip, pelvis and thorax in unilateral weight bearing.* **Tateuchi H, Wada O, Ichihashi N.** 3, Kyoto : Hum Mov Sci., 2011, Vol. 30, pp. 566-73. 1872-7646.

71. *Effect of feet hyperpronation on pelvic alignment in a standing position.* **Khamis S, Yizhar Z.** Tel Aviv : Gait Posture, 2007, Vol. 1, pp. 127-34. 1879-2219.

72. *The mechanical relationship between the rearfoot, pelvis and low-back.* **Duval K, Lam T, Sanderson D.** 4, Vancouver : Vancouver, 2010, Vol. 32, pp. 637-40. 1879-2219.

73. *Foot function and low back pain.* **Bird AR, Payne CB.** Victoria : The Foot., 1999, Vol. 9, pp. 175-180. 0958-2592.

74. *Foot-ground pressure pattern of flexible flatfoot in children, with and without correction of calcaneovalgus.* **Aharonson Z, Arcan M, Steinback TV.** Tel Aviv : Clin Orthop Relat Res., 1992, Vol. 278, pp. 177-82. 1528-1132 .

75. *Structural and functional predictors of regional peak pressures under the foot during walking.* **Morag E, Cavanagh PR.** 4, Penn : J Biomech., 1999, Vol. 32, pp. 359-70.

76. *Differences in Plantar Foot Pressure and COP between Flat and Normal Feet During Walking.* **Tae Han J, Mo Koo H, Jung JM, Jung Kim Y, Hoon Lee J.** 4, Busan : J Phys Ther Sci., 2011, Vol. 23, pp. 683-85.

77. *Biomechanical analysis of functional adaptation of metatarsal bones in statically deformed feet.* **Madjarevic M, Kolundzic R, Trkulja V, Mirkovic M, Pecina M.** 1, Zagreb : Int Orthop., 2009, Vol. 33, pp. 157-63. 1432-5195.

78. *A Cochrane review of the evidence for non-surgical interventions for flexible pediatric flat feet* . **EVANS A.M., ROME K.** 1, Auckland : European Journal of Physical and Rehabilitation Medicine, 2011, Vol. 47.

79. *The Dynamic Stabilizing Innersole System (DSIS): the management of hyperpronation in children.* **Jay RM, Schoenhaus HD, Seymour C, Gamble S.** 2, Philadelphia : J Foot Ankle Surg., 1995, Vol. 34, pp. 124-31. 1067-2516.

80. *Foot problems in children presented to the family physician: a comparison between 1987 and 2001.* **Krul M, Van der Wouden JC, Schellevis FG, Van Suijlekom-Smit LW, Koes BW.** Rotterdam : FamPra Oxford, 2009, pp. 1-6. 1460-2229.

81. *Risk factors that may adversely modify the natural history of the pediatric pronated foot.* **Napolitano C, Walsh S, Mahoney L, McCrea J.** 3, Illinois : Clin Podiatr Med Surg., 2000, Vol. 17, pp. 397-417.

82. *Evaluation and treatment of symptomatic pes planus.* **Yeagerman SE, Cross MB, Positano R, Doyle SM.** 1, NY : Curr Opin Pediatr, 2011, Vol. 23, pp. 60-7. PMID: 21169838.

83. *Flexible Flatfoot in Children and Adolescents.* **Mosca, V.S.** 2, Washington : J Child Orthop, 2010, J Child Orthop, Vol. 4.

84. *Development of the child's arch.* **Gould, N., Moreland, M., Alvarez, R., Trevino, S., Fenwick, J.** 5, Burlington : Foot Ankle Journal, 1989, Vol. 9, pp. 241-5. PMID: 2731836.

85. *Screening for foot problems in children: is this practice justifiable?* **AM, Evans.** 18, Auckland : Journal of Foot and Ankle Research, 2012, Vol. 5. 1757-1146.

86. *Calculation of staheli's plantar arch index and prevalence of flat feet: a study with 100 children aged 5-9 years.* **Hernandez AJ, Kimura LK, Laraya MH, Fávaro E.** 2, Sao Paulo : Acta Ortopédica Brasileira, 2007, Vol. 15. 1413-7852.

87. **Wheeless, C.R.** Flat feet. *Wheeless Textbook of ORT.* [Online] Duke Uni Med Center, Jul 2007. http://www.wheelessonline.com/ortho/pes_planus_flat_foot.

88. **Nordqvist, C.** What are flat feet? What Causes flat feet? *Medical News Today.* [Online] Oct 2009. http://www.medicalnewstoday.com/articles/168608.php.

89. *Physical treatment of foot deformities in childhood.* 3, Belgrade : Acta Chir Iugosl., 2011, Vol. 58, pp. 113-6. 0354-950X.

90. *Diagnosis and treatment of pediatric flatfoot.* **Harris EJ, Vanore JV, Thomas JL, Kravitz SR, Mendelson SA, Mendicino RW, Silvani SH, Gassen SC.** 6, IL : J Foot Ankle Surg., 2004, Vol. 43, pp. 341-73. 1542-2224.

91. *Foot examination in the period of development.* **Slavkovi NS, Vukasinović ZS, Bascarević ZL.** 3, Belgrade : Acta Chir Iugosl., 2011, Vol. 58, pp. 91-5. 0354950X.

92. *The paediatric flat foot proforma (p-FFP): improved and abridged following a reproducibility study.* **Evans AM, Nicholson H, Zakarias N.** South Australia : J Foot Ankle Res., 2009, Vol. 2, p. 25. 1757-1146.

93. *Foot type classification: a critical review of current methods.* **Razeghi M, Batt ME.** 3, Nottingham : Gait Posture., 2002, Vol. 15.

94. *Assessment of the medial longitudinal arch in children and adolescents with obesity: footprints and radiographic study.* **Villarroya MA, Esquivel JM, Tomás C, Moreno LA, Buenafé A, Bueno G.** 5, Zaragoza : Eur J Pediatr, 2009, Vol. 168, pp. 559-567. 1432-1076.

95. *Footprint analysis of flatfoot in preschool-aged children.* **Chen KC, Yeh CJ, Kuo JF, Hsieh CL, Yang SF, Wang CH.** 5, Taichung : Eur J Pediatr., 2011, Vol. 170, pp. 611-7. 1432-1076.

96. *A digital photographic measurement method for quantifying foot posture: validity, reliability, and descriptive data.* **Cobb SC, James CR, Hjertstedt M, Kruk J.** 1, Milwaukee : J Athl Train., 2011, Vol. 46, pp. 20-30.

97. *Temporal parameters and patterns of the foot roll over during walking: normative data for healthy adults.* **Blanc Y, Balmer C, Landis T, Vingerhoets F.** 2, Geneva : Gait & Posture, 1999, Vol. 10, pp. 97-108.

98. *The development of mature gait.* **Sutherland DH, Olshen R, Cooper L, Woo SL.** 3, San Diego : J Bone Joint Surg Am., 1980, Vol. 62, pp. 336-53.

99. *The foot posture index, ankle lunge test, Beighton scale and the lower limb assessment score in healthy children: a reliability study.* **Evans AM, Rome K, Peet L.** 1, Auckland : J Foot Ankle Res., 2012, Vol. 5. 1757-1146.

100. *The feet of overweight and obese young children: are they flat or fat?* **Mickle KJ, Steele JR, Munro BJ.** 11, NSW : Obesity (Silver Spring), 2006, Vol. 14, pp. 1949-53.

101. *Does excess mass affect plantar pressure in young children?* **Mickle KJ, Steele JR, Munro BJ.** 3, NSW : Int J Pediatr Obes., 2006, Vol. 1, pp. 183-188. 17477166.

102. *Three-dimensional measurement of foot arch in preschool children.* **Chang HW, Lin CJ, Kuo LC, Tsai MJ, Chieh HF, Su FC.** Tainan : Biomed Eng Online, 2012, Vol. 11.

103. *The longitudinal arch. A survey of eight hundred and eighty-two feet in normal children and adults.* **Staheli LT, Chew DE, Corbett M.** 3, Washington : J Bone Joint Surg Am., 1987, Vol. 69, pp. 426-8.

104. *Review for the generalist: evaluation of pediatric foot and ankle pain.* **KM, Houghton.** 6, Vancouver : Pediatr Rheumatol Online J., 2008, Vol. 9, p. 6.

105. *The relationship of static foot structure to dynamic foot function.* **Cavanagh PR, Morag E, Boulton AJ, Young MJ, Deffner KT, Pammer SE.** 3, Penn : J Biomech., 1997, Vol. 30, pp. 243-50.

106. *The Effect of Gross motor therapy and orthotic intervention in children with hypotonia and flexible flatfeet.* **Ross CG, Shore S.** California : J Prosthet Orthot., 2011, Vol. 23, pp. 149-154. 1040-8800..

107. *The diagnosis of flat foot in the child.* **Rose GK, Welton EA, Marshall T.** 1, Shropshire : J Bone Joint Surg Br., 1985, Vol. 67, pp. 71-78. 2049-4408.

108. *Rehabilitative treatment in flexible flatfoot: a perspective cohort study.* **Riccio I, Gimigliano F, Gimigliano R, Porpora G, Iolascon G.** 3, Naples : Chir Organi Mov., 2009, Vol. 93, pp. 101-7. 1973-2538.

109. *The efficacy of nonsurgical interventions for pediatric flexible flat foot: a critical review.* **Jane MacKenzie A, Rome K, Evans AM.** 8, Auckland : J Pediatr Orthop., 2012, Vol. 32, pp. 830-4. 1539-2570.

110. *Corrective shoes and inserts as treatment for flexible flatfoot in infants and children.* **Wenger DR, Mauldin D, Speck G, Morgan D, Lieber RL.** 6, Dallas : J Bone Joint Surg Am., 1989, Vol. 71, pp. 800-10. 0021-9355.

111. *How should you treat a child with flat feet?* **Vanstory M, Mackler L.** 6, North Carolina : Journal of Family Practice, 2010, Vol. 59.

112. *Combined technique for surgical correction of pediatric severe flexible flatfoot.* **Cohen-Sobel E, Giorgini R, Velez Z.** 2, New York : J Foot Ankle Surg., 1995, Vol. 34, pp. 183-94. 1067-2516.

113. *Flat foot. A preliminary report of an operation for severe cases.* **BS, Jones.** 3, Cape Town : J Bone Joint Surg Br., 1975, Vol. 57, pp. 279-82.

114. *The paediatric flat foot and general anthropometry in 140 Australian school children aged 7 - 10 years.* **AM, Evans.** 1, Adelaide : J Foot Ankle Res., 2011, Vol. 4, p. 12. 1757-1146.

115. *Effect of children's shoes on gait: a systematic review and meta-analysis.* **Wegener C, Hunt AE, Vanwanseele B, Burns J, Smith RM.** 3, Sydney : J Foot Ankle Res., 2011, Vol. 4.

116. *Shoes for children: a review.* **LT, Staheli.** 2, Seattle : Pediatrics, 1991, Vol. 88, pp. 371-5. 1098-4275.

117. *The influence of footwear on the prevalence of flat foot. A survey of 1846 skeletally mature persons.* **Sachithanandam V, Joseph B.** 2, Manipal : J Bone Joint Surg Br., 1995, Vol. 77, pp. 254-7. 0301-620X/95/2941.

118. *Relationship between selected anthropometric variables and prevalence of flatfoot among urban and rural school children in south west Nigeria.* **Abolarin TO, Aiyegbusi AI, Tella BA, Akinbo SR.** 2, Lagos : Nig Q J Hosp Med., 2011, Vol. 21, pp. 135-40. 0189-2657.

Appendix I

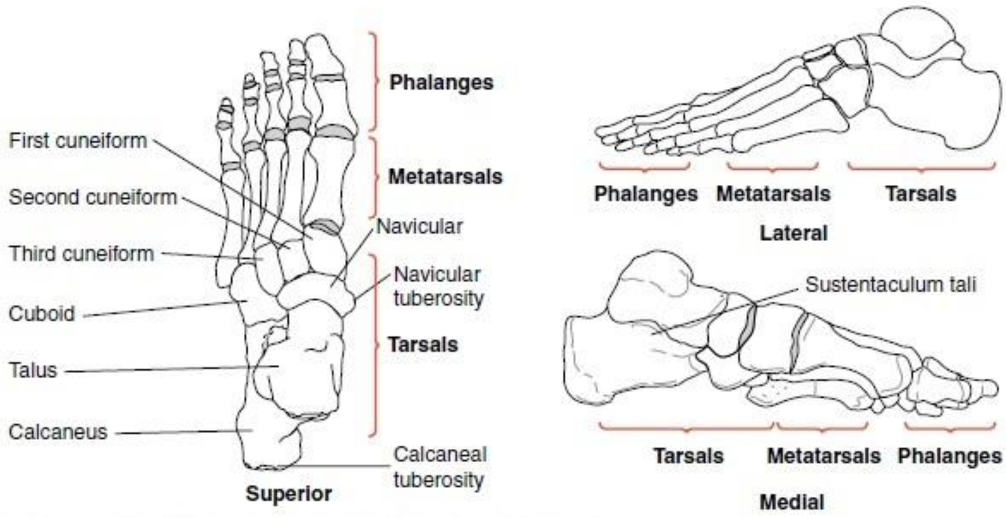

Figure 1. Bones of the (left) foot (10)

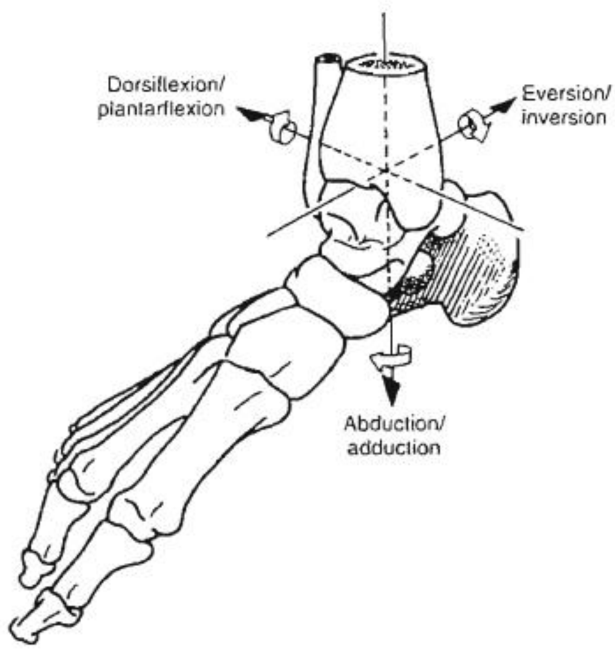

Figure 2. Foot motion planes (9).

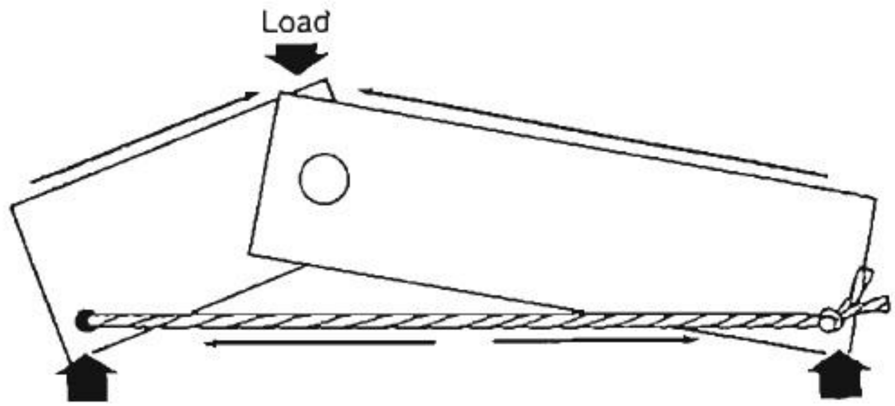

Figure 3. Truss model representing the MLA of the foot. The 2 struts (bones of the feet) are connected at the base by a tie rod (plantar fascia) (9).

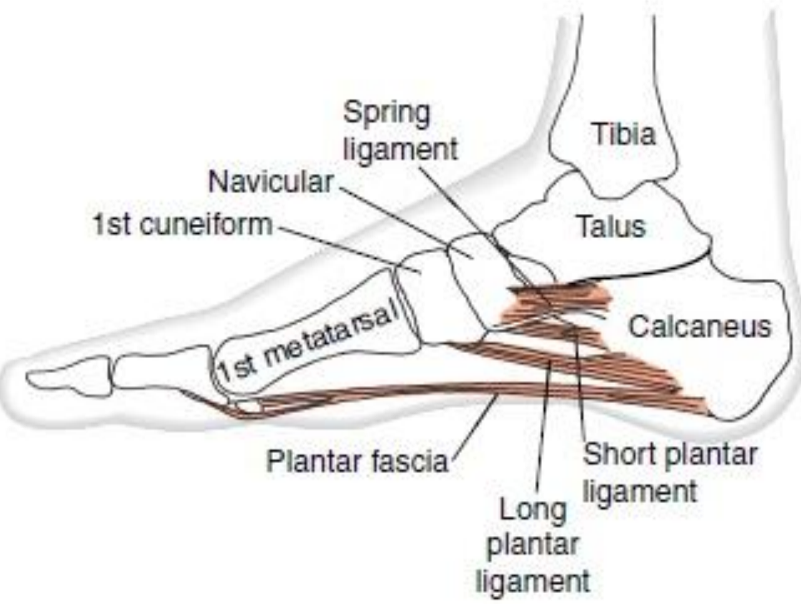

Figure 4. Support structures of the (right) foot and arch (10).

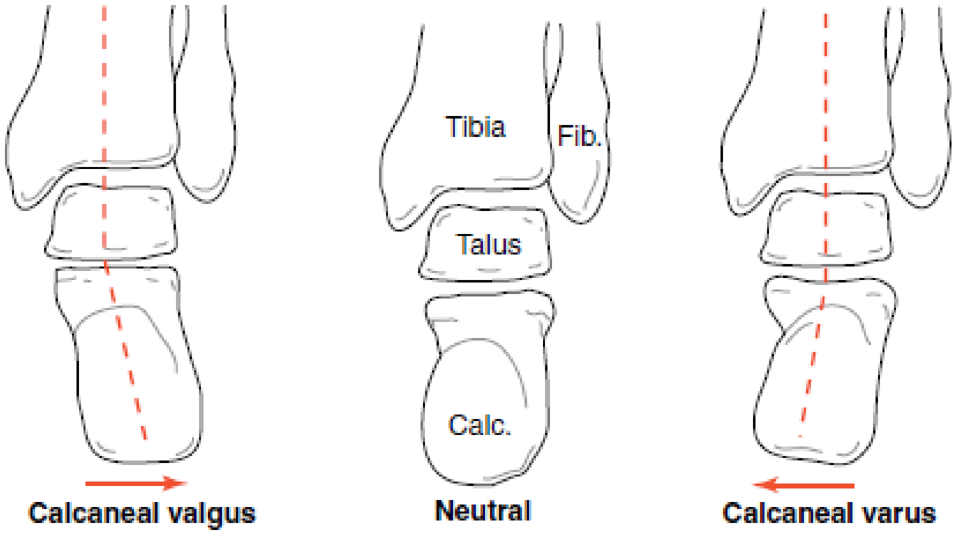

Figure 5. Calcaneovalgus and calcaneovarus positions illustrated (10).

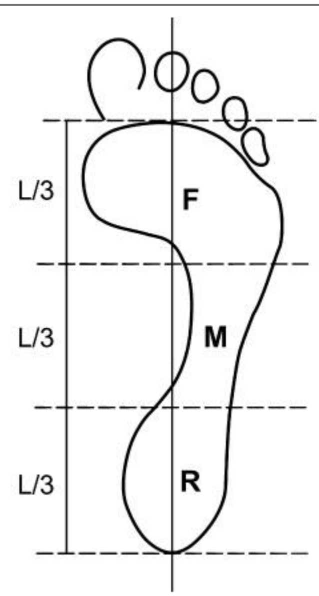

Fig. 4. Graphical illustration of footprint length division into three equal areas for the calculation of AI (L/3). AI, the ratio of the area of the middle third of the toe less footprint to the total toeless footprint area (M/(F+M+R)); in which AI, Arch Index; F, forefoot area; M, midfoot area; R, rear foot area.

Figure 6. An illustration of the Arch Index (17)

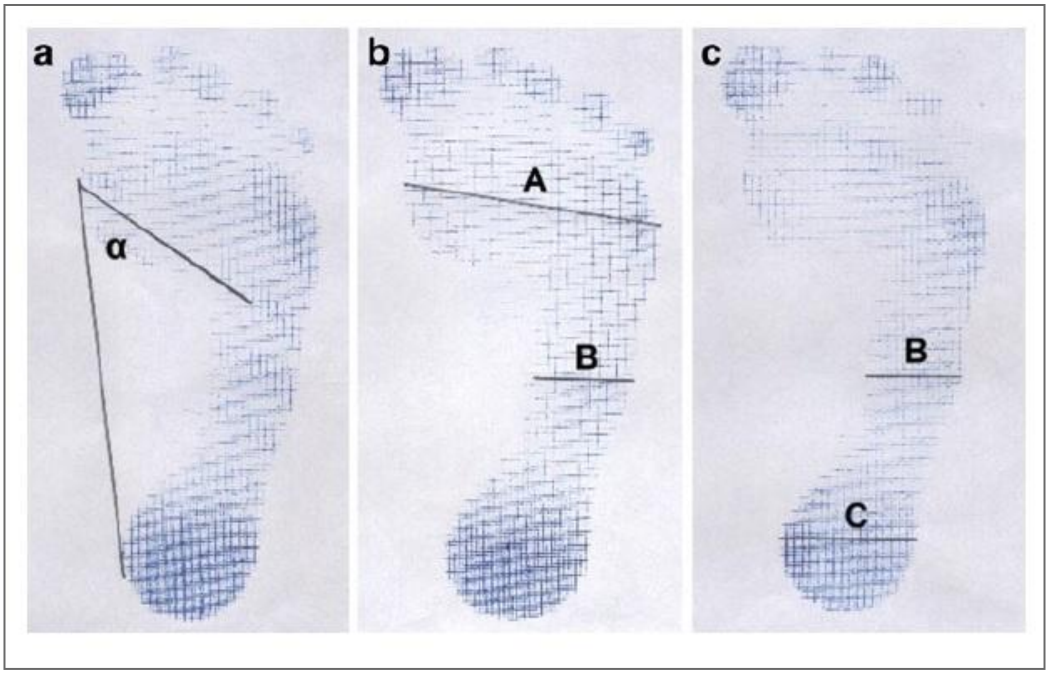

Figure 7. Illustrations of a) Clarke's angle = a, b) CSI = B/A x 100%, c) Staheli's index = B/C x 100% (17)

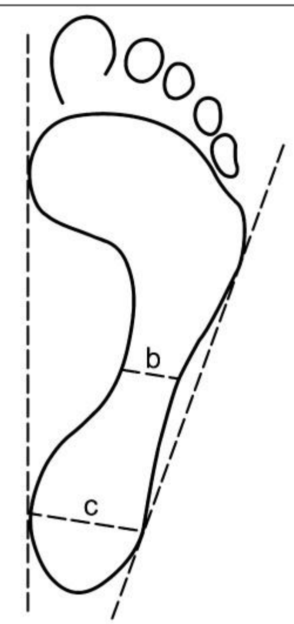

Fig. 2. Graphical illustration of lines used for the calculation of SI. SI = b/c; in which (SI) Staheli Index; (b) minimal width of the MLA's area; (c) maximal width of the heel print, being (c) parallel to (b).

Figure 8. Illustration of Staheli's Arch Index (17)

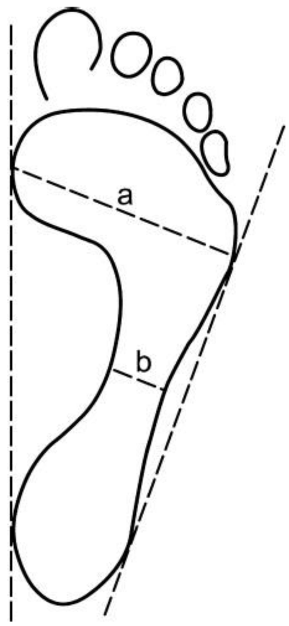

Fig. 1. Graphical illustration of lines used for the calculation of CSI. CSI = b/a; in which (CSI) Chippaux-Smirak Index; (a) maximal width of the metatarsal print; (b) minimal width of the MLA's area, being (b) parallel to (a).

Figure 9. An illustration of the CSI (17)

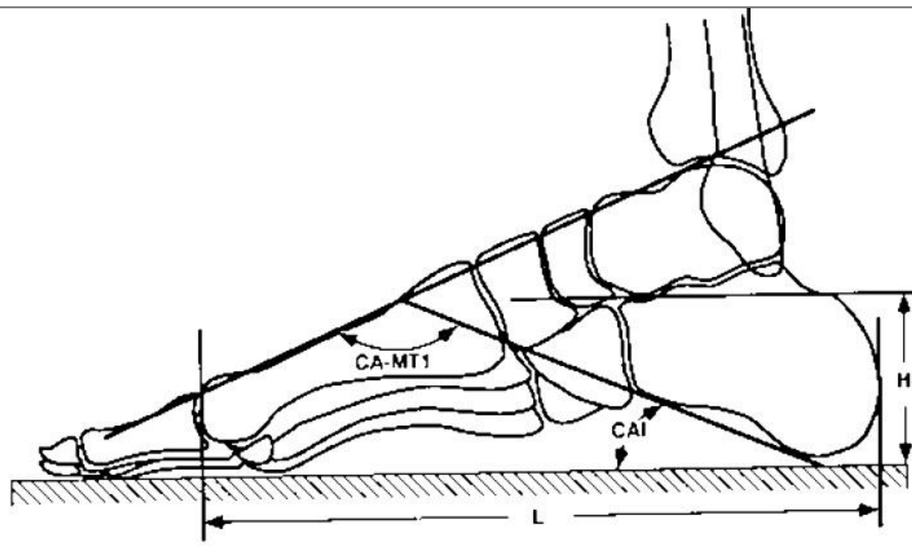

Fig. 3. Radiographic parameters defining MLA measured on standing lateral X-ray. CIA, Calcaneal inclination angle; H/L, height to length ratio; CA–MT1, calcaneal–first metatarsal angle (from Saltzman et al. [23]).

Figure 10. Radiographic parameters on a lateral x-ray to define the MLA (93)

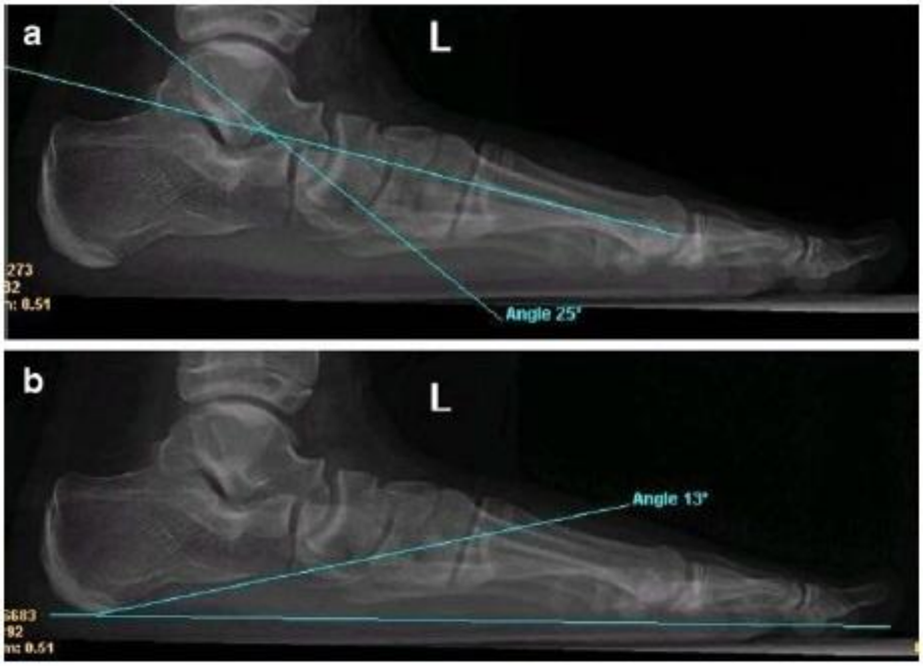

Figure 11. Radiographic parameters, a) Talus-first MT angle, b) Calcaneal inclination angle (93).

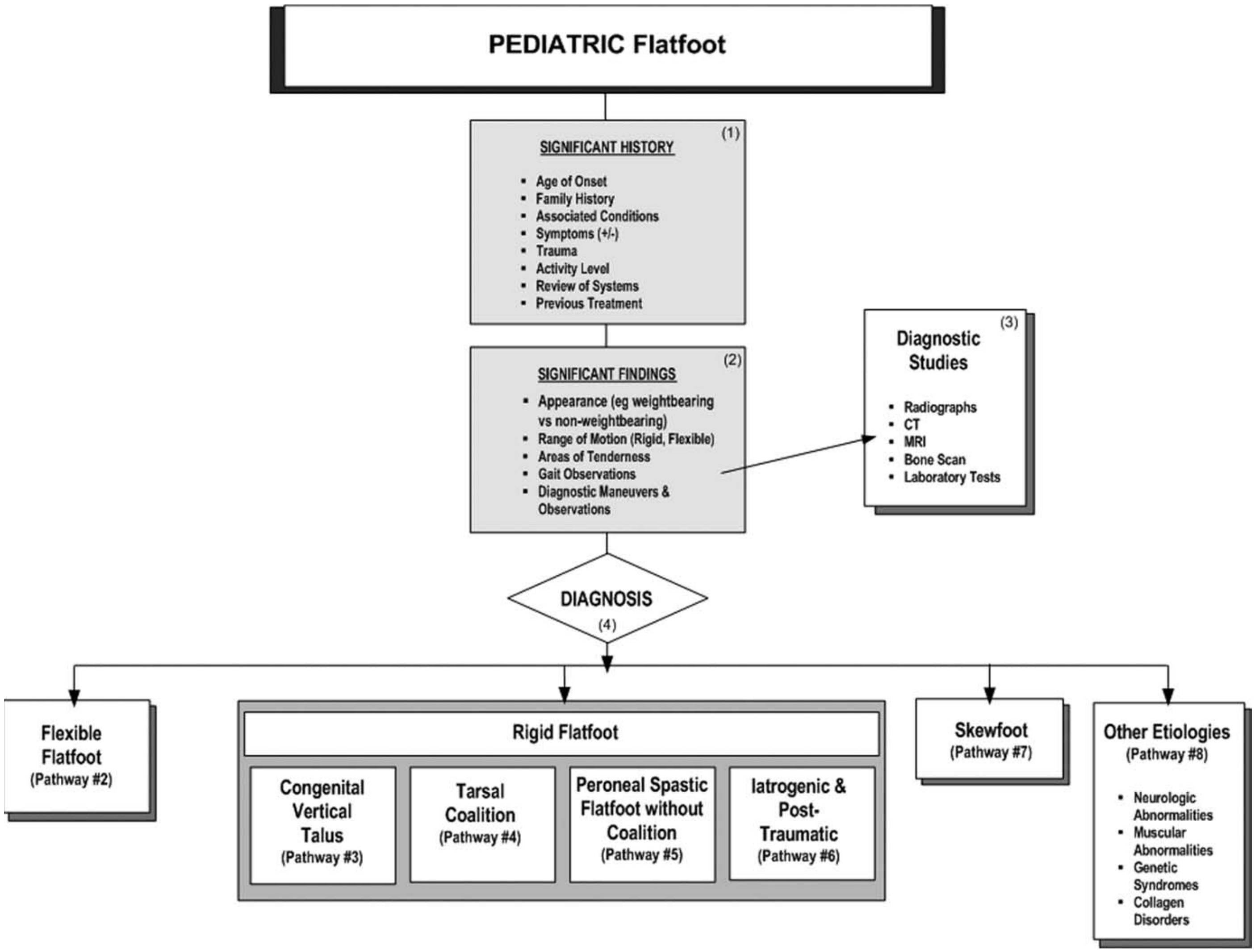

Figure 12. Outline of main points for diagnosing FF in children (adopted from a clincal practice guideline, 90)

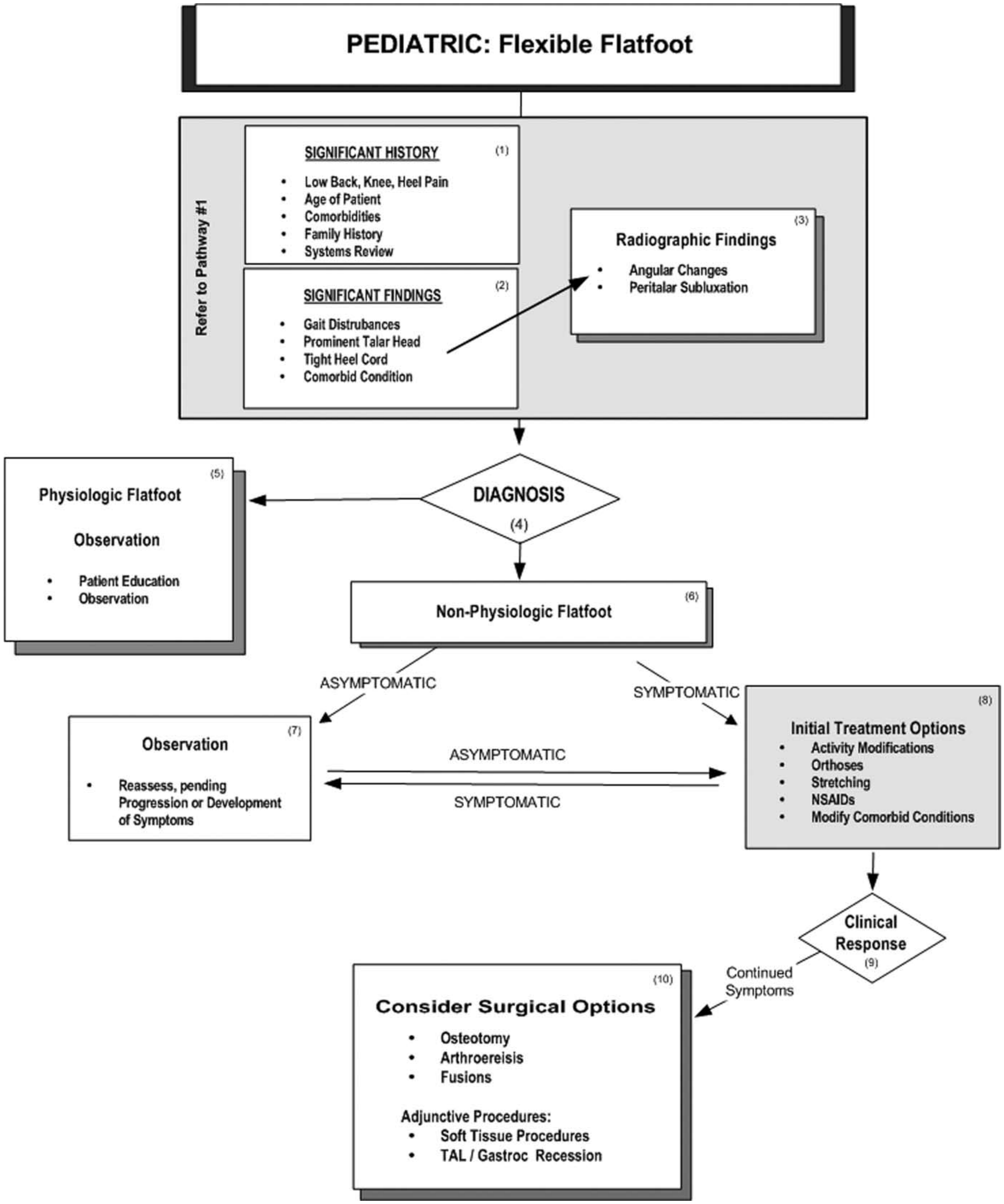

Figure 13. Pathway to diagnosing and treating pediatric FFF (adopted from clinical practice guideline, 90)

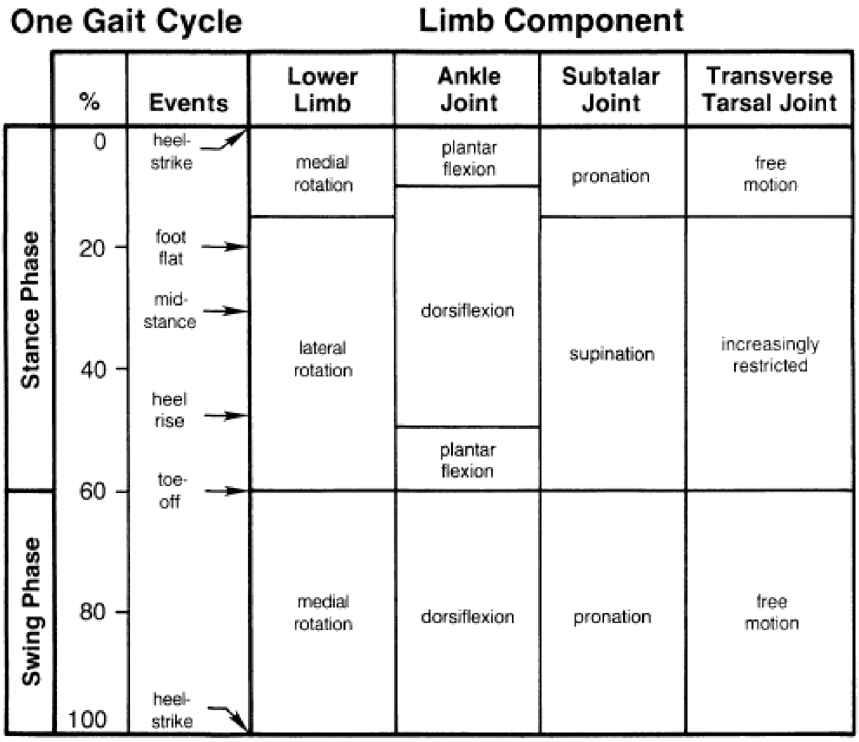

Figure 14. Summary of phases of the gait cycle and its LE components (47)

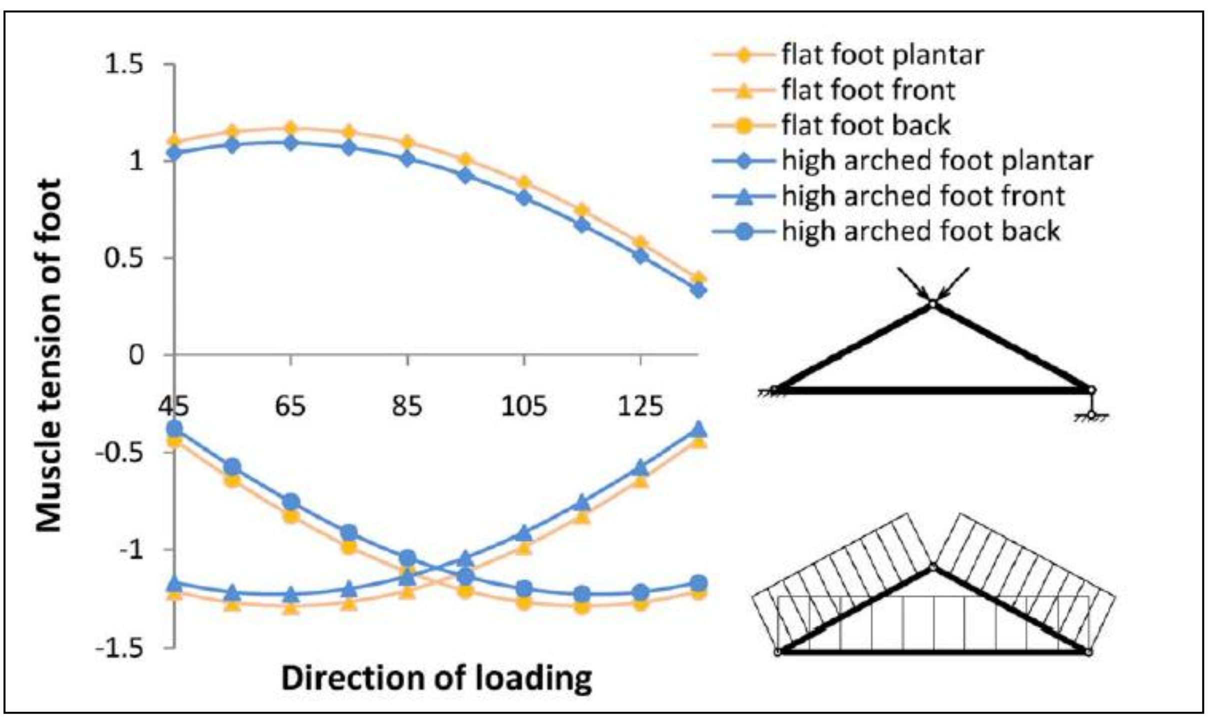

Figure 15. Relationship between muscle tension and load (60)

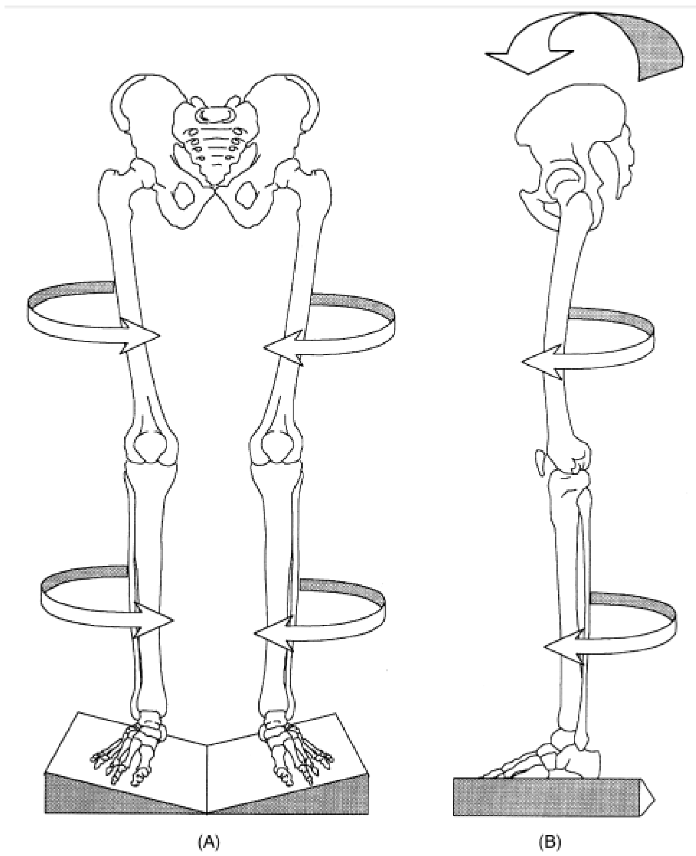

Figure 16. Schematic representation of the proposed chain reaction of the upper segments to induced hyperpronation (71)

Appendix II

Table 1. A foot type classification scheme (93)

Foot type classification scheme based on Root et al. (from Song et al. [28])

Biomechanical examination	Planus	Rectus (normal)	Cavus
Resting calcaneal stance position (RCS)	RCS ≥ 4° valgus	2° varus ≤ RCS ≤ 2° valgus	RCS ≥ 0° varus
Subtalar joint neutral position (SJN)	Not relevant	2° varus ≤ SJN ≤ 2° valgus	SJN ≥ 4° varus
Forefoot to rearfoot alignment (FRA)	FRA ≥ 4° varus	2° varus ≤ FRA ≤ 2° valgus	FRA ≥ 4° valgus

Table 2. Criteria for classifying feet based on structure and alignment (93)

Criteria for classifying feet into different types based on a combination of characteristics of structure and alignment (from Sneyers et al. [30])

Criteria for classification	Planus	Rectus (normal)	Cavus
Arch height	Low	Normal	High
Leg to rearfoot alignment	Heel valgus	Neither varus nor valgus	Heel varus
Forefoot to rearfoot alignment	Forefoot varus	Neither varus nor valgus	Forefoot valgus

Table 3. Three kinds of analysis distributed according to age group (adopted from study 95)

	Age				Total (*n*=2,638)
	3 years (*n*=440)	4 years (*n*=782)	5 years (*n*=1,044)	6 years (*n*=372)	
CA (°)	12.9 (0–46.4)	15.2 (0–53.5)	16.2 (0–52.6)	17.4 (0.9–53.7)	15.5 (0–53.7)
CSI (%)	65.7 (24.8–117.7)	62.0 (20.5–89.2)	60.0 (22.0–86.1)	58.1 (13.8–91.3)	61.3 (13.8–117.7)
AI (%)	112.2 (48.9–184.0)	107.8 (31.1–155.5)	105.4 (36.1–165.7)	101 (26.1–169.7)	107.5 (26.1–184.0)
Flatfoot, *n* (%)	258 (58.64)	382 (48.85)	401 (38.41)	120 (32.26)	1,161 (44.01)

Values are given as median (range: minimum–maximum)

Table 4. The studies which returned prevalence estimates, reported on children of disparate ages, varying samples, and used a range of assessment and classification methods (78)

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

Table 5. The new p-FFP - Treatment is directed for the typical flexible flat foot according to sub-type assessment i.e. type A1, symptomatic/'red light', treat; type A2, asymptomatic-non-developmental/'orange light', monitor; type A3, asymptomatic-developmental/'green light', leave alone (92).

paediatric Flat Foot Proforma (p-FFP) Child's name: ______________________ Age:_____

History • Family Hx • Associations • Symptoms • Trauma • Activity • Systems review • Previous Tx

Findings • Tender areas *. y/n . site/s* • Gait *barefoot shoes on . limp y/n . AOG* • Obesity (ok / + / ++)

DIAGNOSIS	**A. Typical flexible flatfoot +/- other factors** Neurological eg Cerebral palsy, hypotonia Muscular eg Muscular dystrophies Genetic eg Down's, Marfan's Collagen eg Ehler's Danlos, ligament laxity	**B. Rigid flatfoot** Vertical talus Tarsal coalition Peroneal spasm Iatrogenic Trauma	**C. Skewfoot** Metatarsus adductus

A. Typical flexible flatfoot **1. Symptomatic*** *or* **Asymptomatic**

2. Non-developmental* (*Structural deformity* progressing with age) *or* **3. Developmental** (*Structural deformity* reducing with age)

Observe	L	R	Measure	L	R
Medial arch height (ok / reduced)			Navicular height (mm)		
Heel eversion (ok / more everted)			RCSP (°inv/ev)		
Heel inversion with tip toe (y / n)			**Consider**		
Tibial, knee positions (med / 0 / lat)			Muscle tone, ligament laxity (y / n)		

Action plan:
Date:

1 TREAT
2 MONITOR
3 LEAVE ALONE

To be used in conjunction with:
Diagnosis & treatment of pediatric flatfoot. Harris EJ et al, *J Foot & Ankle Surg* 43(6): 341-370, 2004
The flat-footed child – to treat or not to treat, what is the clinician to do? Evans AM, *J Am Podiatr Med Assoc* (in press), 2008

Table 6. Therapeutic exercises for FFF (108)

Aim	Exercises and activities
Flexibility	pROM exercise of ankle and all foot joints
	Global movement to bring anterior and posterior foot columns closer together
	Stretching of triceps surae and lateral peroneus brevis muscles in order to induce varus and adduction of the foot
Muscle strengthening	Anterior and posterior tibialis muscles and the flexor hallucis longus to counteract valgus
	Intrinsic, interosseus plantaris muscles and the abductor hallucis in order to prevent anterior arch flattening
	Global activation/movement of the muscles involved in maintaining the medial arch and the varus with and without load
	Unipedal weight bearing
	Toe walking
Proprioception and postural balance	Toe and heel walking
	Unipedal weight bearing (to make the foot cavus after dynamic pronation of the forefoot)
	Descending an inclined plane

Table 7. Summary of movements of LE with their muscle actions (own table adopted from 8, 10, 46)

Movement	Muscles
DF of ankle	Tibialis anterior, peroneus tertius, extensor digitorum longus, extensor hallucis longus.
PF of ankle	Gastrocnemius, soleus, peroneus longus, peroneus brevis, flexor digitorum longus, flexor hallucis longus
INV of foot	Tibialis anterior, tibialis posterior
EV of foot	Peroneus longus, brevis and tertius
Toe F	Flexor digitorum longus, flexor hallucis longus
Toe EXT	Extensor digitorum longus, extensor hallucis longus
F of knee	Hamstrings group of muscles
E of knee	Quadriceps, rectus femoris
F of hip	Iliopsoas, rectus femoris, pectineus, sartorius, TFL
E of hip	Gluteus maximus, hamstrings
ABD of hip	Sartorius, gluteus medius/minimus, TFL
ADD of hip	Pectineus, adductor longus/brevis + magnus, gracilis
ER of hip	Sartorius, gluteus maximus, piriformis, gemellus sup./inf., obturator internus, quadratus femoris
IR of hip	Gluteus minimus

Table 8. Means and standard deviations for all the parameters for the normal and low-arched groups (58)

	Normal arched				Low arched			
	Right		Left		Right		Left	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Range anterior pelvic tilt	**3.8°***	±1.3	4.2°	±1.2	**4.7°***	±3.2	4.7°	±3.1
Pelvic rotation at HS	6.1°	±3.2	7.4°	±4.8	6.7°	±2.7	6.5°	±3.4
Max pelvic rotation (ST)	3.4°	±3.4	3.8°	±5.1	4.2°	±3.2	3.8°	±2.7
Max pelvic obliquity (ST)	6.2°	±1.7	5.9°	±2.4	7.2°	±2.6	6.6°	±3.2
Min pelvic obliquity (SW)	–5.7°	±2.2	–6.2°	±1.7	–6.8°	±2.9	–7.0°	±2.6
Range hip flexion	44.7°	±5.2	44.0°	±4.4	47.7°	±5.2	46.5	±4.0
Hip flexion at HS	32.7°	±4.8	31.8°	±5.4	32.5°	±6.6	34.8°	±6.9
Min hip flexion	–10.0°	±5.3	–9.7°	±4.7	–11.6°	±7.8	–10.7°	±8.0
Hip rotation at HS	–8.4°	±7.0	–9.5°	±4.4	–11.3°	±5.6	–14.5°	±8.9
Mean hip rotation (ST)	**–0.9°***	±4.5	**–1.9°***	±2.9	**–4.7°***	±3.5	**–6.4°***	±5.9
Max hip abduction (ST)	7.9°	±3.5	7.3°	±2.9	9.8°	±3.8	10.0°	±4.2
Min hip abduction (SW)	–2.2°	±2.9	–1.7°	±2.6	–1.5°	±2.4	–0.8°	±3.2
Knee flexion at HS	7.7°	±4.1	6.2°	±6.0	6.6°	±4.1	9.1°	±3.9
Max knee flexion (SW)	60.3°	±3.5	60.7°	±4.6	61.4°	±5.1	62.7°	±4.4
Timing max knee flexion	75%	±2.0	75%	±1.0	76%	±1.0	76%	±1.0
Min knee flexion (ST)	4.2°	±3.5	4.2°	±4.8	2.9°	±3.7	5.5°	±3.8
Knee varus/valgus at HS	0.5°	±2.2	**0.7°***	±2.6	–0.8°	±2.7	**–2.1°***	±2.3
Range knee varus/valgus	12.3°	±5.5	12.3°	±4.2	13.8°	±5.0	14.2°	±5.6
Ankle flexion at HS	0.1°	±6.7	–0.4°	±6.8	2.4°	±3.8	1.6°	±7.7
Max ankle flexion (ST)	15.9°	±4.3	16.2°	±4.4	15.7°	±3.0	15.9°	±3.6
Min ankle flexion (SW)	–17.7°	±8.7	–21.2°	±10.1	–14.4°	±7.6	–20.7°	±14.3
Max foot progression angle (ST)	3.0°	±1.4	2.8°	±1.2	2.3°	±1.5	2.4°	±1.7

Note: HS denotes heel strike, ST denotes stance phase, SW denotes swing phase of the gait cycle. In rotations positive values are internal and negative values external, in flexion variables flexion is positive and extension is negative, adduction is positive and abduction negative, and knee varus is positive and valgus negative. All significant difference ($p < 0.05$) have been bolded.

* A significant difference between groups.

Table 9. Injury patterns of runners (participants in study 63)

	High arch	Low arch
Knee	11	20
Foot/ankle	33	24
Bone	14	7
Soft tissue	42	56

Table 10. Theoretical mechanisms that interrelate foot posture and LBP (73)

a. Heel height of footwear;
b. inadequate shock absorption;
c. factors related to excessive foot pronation;
d. functional limb length discrepancy;
e. sagittal plane blockade.