PREVALENCE AND ASSOCIATED FACTORS OF FLAT FOOT AMONG 6 TO 16 AGED CHINESE CHILDREN AND ADOLESCENTS: A CROSS-SECTIONAL STUDY

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Prevalence and Associated Factors of Flat Foot among 6 to 16 Aged Chinese Children and Adolescents: A Cross-sectional Study

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requirements for the degree of

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Certificate of Originality

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Leung Ka Wing

Abstract

Flat foot in early-age children, believed by many researchers, was a transitional growing process. It appeared to be a flat foot because there was a fat pad under the medial longitudinal arch. This kind of non-pathological foot condition would disappear during grow up (J. J. Echarri & J. F. Forriol, 2003). Dare & Dodwell shared a similar view that due to ligament laxity, almost all infants and children had flat feet who were aged under 6. The medial arch would be more visible when they were growing up during the first ten years of life (M. D. Dare & R. E. Dodwell, 2014). Furthermore, over-weighted individuals were commonly seen in many developed countries and the number was growing for all ages people globally. There were about 30% of the kids in Spain were classified as obese. As for the musculoskeletal system, obesity or being overweight was another key factor promoting the acquisition of flatten arches and might lead to discomfort or pain in the lower limb as a result (Jiménez-Ormeño, Aguado, Delgado-Abellán, Mecerreyes, & Alegre, 2013). In addition to the obesity issue, gender differences in foot morphology changes were another popular topic in western countries. American boys experienced their feet growing peak at age 13 while it was age 11 for U.S. girls. In Germany, male kids' feet stopped growing at age 15 and it was 13 for girls in the country. As for Greek society, boys showed a lower arch tendency than girls throughout the ages of 13 to 17 (Xu, Li, Hong, & Wang, 2019). Delgado-Abellán,

Aguado, Jiménez-Ormeño, Mecerreyes, and Alegre concluded in their study done in Spain that the growth trends of the two sexes were similar in general; however, the differences appeared at the age of 8 and 10 for boys and girls respectively (Delgado-Abellán, Aguado, Jiménez-Ormeño, Mecerreyes, & Alegre, 2014). These findings were considered close to those results in previous works in Hong Kong (China), Glasglow (UK), and Germany.

Owing to the high prevalence of flat feet in the early stage of human life, a substantial number of studies were on this topic. Some of them focused on the foot length growth patterns, some investigated the differences between the two genders in different age ranges. There were more parameters had been analyzed; BMI, width, circumference, and footprint were examples. However, among those reviewed studies, aiming at the growing pattern of the kid's arch shapes was rare.

Through studying foot arch shapes of 8955 boys and girls at the ages of 6 to 16 with 3D foot data capture system had been conducted. The results showed that Arch Index (AI) had a strong correlation with Arch Length Ratio (AHR), which was the strongest association among all parameters. And, therefore, a regression had been set up on these two variables to form an equation for clinical practice to classify different arch types

by Medial Arch Length (MAL) and Arch Height (AH) for the age range of 6 to 16.

It was found that the correlation of the Arch Index (AI) and Valgus Index (VI) was the second strongest among all variables, which was easily understandable because both indexes were flat foot related. The last meaningful associations were paired up as Age and AI, Age and VI, Age and AHR, among these variable pairs possessed moderately strong correlations. While other parameters showed very weak or no correlations in this study. Finally, both sexes' foot arch started a rapid growth at age 6. It was found that girls' arch got mature at age 12 while boys' arch slowed down growth at age 13. Furthermore, throughout the growing period of age from 6 to 11, females grew faster than males. From age 12 onwards, the arch shapes of the two groups did not indicate a significant discrepancy.

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List of abbreviations

AHR	Arch Height Ratio
AI	Arch Index
AL	Arch Length
BMI	Body Mass Index
BW	Body Weight
FL	Foot Length
MAH	Medial Arch Height
MAL	Medial Arch Length
MLA	Medial Longitudinal Arch
VI	Valgus Index

Chapter 1 Introduction

1.1. Objectives of the study

The objective of this study was to investigate foot morphological changes in kids aged from 6 to 16. By analyzing the distributions of the data and the associated independent variables, a simple linear equation for determining flat feet was generated for clinical practice. In addition, the correlations between common foot arch describing indexes and some other demographical variables were analyzed, to determine how much correlations among those factors. Finally, the foot anthropometric data were captured. A whole set of normalized data for each foot was generated, and a topological data distribution could be set up. A clear growing pattern and prevalence of foot arches were expected. One of the growing stages was Foot Arch Maturity, which could be observed as well.

1.2. Scope of the study

In this study, 8955 subjects aged from six to sixteen, 5218 or 58.3% male and 3737 or 41.7% female subjects were measured. The subjects were recruited randomly from 19 schools in five areas across China. Provided that all the subjects had no history of injuries or other visible deformities in the lower limbs. Other than collecting the 3D foot data, a questionnaire (Appendix A) was designed and finished by every subject. The purpose of the questionnaire was to understand more about the subjects' exercising habits and other body conditions.

Various commonly used indexes and data, which were Cavanagh and Rodgers Arch Index (AI), Valgus Index (VI), Body Weight, Height, Foot Length, Gender, Medial Arch Height (MAH), Medial Arch Length (MAL), Regional data, and Pain incidents were measured and record. Frequency summary for categorial data, which were Gender, Regions, and Pain incidences. Descriptive information including AI, VI, BW, height, FL, MAH, and MAL was integrated to determine the growth trend of the kids from ages 6 to 16. The BMI and Arch Height Ratio (AHR) were calculated for correlation and regression analysis.

1.3. Justification and significance of the study

Flexible flat feet were one of the commonest lower limb conditions in children in Hong Kong (Leung, Mak, & Evans, 1998). It was about 15 to 20% of the young Chinese population, which were aged from 4 to 18, had low arch (A. K. L. Leung, J. C. Y. Cheng, & A. F. T. Mak, 2005).

Different levels of lower limb problems such as discomfort, easy fatigue feelings, strain, pain, and other co-morbidity such as plantar fasciitis, osteoarthritis of the knee, chondromalacia patellae, etc., occurred in some patients with symptomatic flexible flat feet. The daily living quality of these patients was compromised (Tsung, Zhang, Mak, & Wong, 2004).

This Project aimed to collect the children and adolescents' foot arch and foot shape data of selected parameters, to analyze the growth and development patterns of the kids' feet ages between 6 to 16, across different cities in China. Medial Arch Height (MAH), Arch Length (AL), MAH/AL (AHR), Cavanagh and Rodgers Arch index (AI), and Valgus Index (VI) were the parameters to be investigated. The distributions and correlations among these parameters at different ages, different regions across China, and Body Mass Index (BMI) were studied as well. These patterns provide a better understanding of the foot development in the population and better diagnosis could be done. Furthermore, regression analysis was performed to formulate an equation to calculate the AI through the most correlated independent variable for flat feet differentiation in daily clinical operations.

Chapter 2 Literatures review

2.1. Flexible flat foot

The human foot consisted of 26 bones and connects to many ligaments, tendons, and muscles. This foot complex performed pronation and supination in every step of ambulation. It was believed that age, gender, race, body weight, and the living environment had a close relationship with the growth of the foot. This body structure grew as age advanced in the early stage of human life. The foot grew in terms of foot length from age 13 to 18. It stopped growing depending on bone maturity in American society. A similar investigation of the same age range in Japan affirmed that foot growth at the same ages was found in a ten thousand subject group (Xu et al., 2019).

2.1.1. Definition of flexible flat feet

Reducing arch height without pain was one of the common characteristics of pes planus, also named flat feet (K.-N. Park, Koh, & Jung, 2022). This disorder could be either congenital or acquired later in life. This condition was either rigid or flexible in the foot structures. The acquired flat feet could be related to ligamentous, muscular, articular, bony, or contractural pathologies (surgeons(ACFAS), 2017). The presence of an abnormal spatial and mechanical relationship between talus and calcaneus involved mainly capsule-ligamentous structures, and the foot in which under weight-bearing conditions (a close kinetic chain situation), the medial longitudinal arch was depressed, and the subtalar joint was pronated accompanying by a calcaneal valgus position. When in non-weight-bearing (an open kinetic chain situation), the arch would be in a more arciform shape compared to the body weight-loaded position. The above condition was defined as flexible flat feet (pes planus).

2.1.2. Background of flat foot

Flat foot as a real deformity was controversial (Atik & Ozyurek, 2014), but still, it was known as a common deformity in children (Aboutorabi et al., 2014), we could find it in childhood or adolescence or even in adulthood (surgeons(ACFAS), 2017). However, there was no absolute agreed definition of the flat foot or paediatric valgus foot (Medina-Alcantara et al., 2019). Singh, et. al. reported that most children's flexible flat feet were asymptomatic, and structural flat feet were less than 0.1%. Early intervention for flexible flat feet could prevent complications of development and stay asymptomatic (Singh, Kumar, Kumar, Srivastava, & Gupta, 2010). While Dare and Dodwell shared an opposite point of view on flat foot (M. D. Dare & R. E. Dodwell, 2014). That is, some of the flat feet were symptomatic. The Medial Longitudinal Arch (MLA) collapsed or disappeared in children. It was a common malformation of children's feet in childhood. This condition would raise some concerns about the normal growing process of the children. Almost all infants were born with flat feet. Most of these flat feet were flexible and flappy throughout the toddler and children's stages (Ezema, Abaraogu, & Okafor, 2014). In the first 2 years after birth, there was no medial longitudinal arch could be seen in the foot due to the abundance of fatty tissue. The arch would develop rapidly from the age of 2-6 years (Aboutorabi et al., 2014). Atik & Ozyurek wrote that a normal longitudinal arch develops from the age of 3 to 5 in most children, and only 4% of them grow with their flexible flat feet into the age of 10 (Atik & Ozyurek, 2014). Kuhn stated that a flat foot was commonly understood as a medial longitudinal arch lower than the averaged parameters. And this foot condition was further described into 4 types: "flexible", "rigid", "congenital" or "acquired". In a standing position (weight-bearing), the medial longitudinal arch was flattened, on the other hand, the arch came back when it was not in a standing position (non-weight-bearing), this foot type was classified as a flexible flat foot (Kuhn, Shibley, Austin, & Yochum, 1999). Jack's test (great toe was dorsiflexed as the plantar fascia tightens) could differentiate a flexible one if the arch showed up again (Atik & Ozyurek, 2014).

Flat foot in early-age children, believed by most researchers, was a transitional growing process. It appeared to be a flat foot because there was a fat pad under the medial longitudinal arch. This kind of non-pathological foot condition would disappear when grown up (J. J. Echarri & J. F. Forriol, 2003). Dare & Dodwell shared a similar view that due to ligament laxity, almost all infants and children had flat feet who were aged under 6. The medial arch would be more visible when they were growing up during the first ten years of life (M. D. Dare & R. E. Dodwell, 2014). Another study proposed that the flat foot incidence rate of the 18-month baby was 97% while it was only 4% in ten-year-old kids. A paper cited by Dare and Dodwell explained that in a population of 835 children subjects, the occurrence of flat foot in kids at the age of 3 to 6 was definite. 54% of 3-year-old kids had a flat foot. 26% of 6-year-old children have the same foot condition. Abich and his team found that 17.6% of overall flat foot prevalence was related to age, gender, BMI, foot pain, school type, and type of shoe wear (Abich, Mihiret, Yihunie Akalu, Gashaw, & Janakiraman, 2020). While in 2009, Chang et al. showed in their study that 59% (1,222 out of 2.083 subjects) were classified as flat foot. In the same study, they found that gender, and body weight was significantly affecting the presence of flat feet (J.-H. Chang et al., 2009).

2.1.3. Possible problems with flexible flat foot

In addition, children with flexible flat feet would feel pain after a long period of standing. Plantar fasciitis, ligament laxity, fatigue, and instability of the internal structure of the foot were the initial symptoms. The excessive mechanical force from the unstable foot structure was transmitted proximally to the knee and hip. What's more, pronation was an essential joint movement in the foot during walking, adapting to uneven surfaces and absorbing shock from the ground. Overpronation in flexible flat feet induced internal rotation of the tibia, which applied critical forces to the lower extremities. The foot condition was believed to be related to a stress fracture, patellofemoral joint pain, backache, and muscle disorders such as Achilles tendinopathy.

Parents might find out about the flat foot condition in children by structural problems and pain in their children. Traditionally, most parents choose a medical shoe for the child to treat the flat foot deformity. And doctors would conventionally prescribe medical shoes for children as well (Aboutorabi et al., 2014).

2.1.4. Treatment

Wagner suggested that an asymptomatic flexible flat foot doesn't need to be treated. For those aged below ten years, the symptomatic flexible flat foot should be tried with foot orthotics initially. If the conservative treatment failed or rigid structural deformity developed, the further diagnosis had to be done (Wagner, Hofbauer, & Matussek, 2013).

Conservative Treatment

The treatment of flexible flat feet could be varying from observation to physiotherapy and orthotic treatments or surgery. Orthotic treatment included custom-made orthoses (UCBL as an example), prefabricated orthoses, arch supports, heel modifications, and medical shoes. It was described that orthoses could control the rate of change of the subtalar joint and its range of motion and restore normal biomechanical movements among the joints in the lower limbs. But, there was limited research relating to the kinematic effect of orthoses, even though Orthoses were commonly, and widely used as a treatment for flexible flat feet (Aboutorabi et al., 2014).

Surgical Treatment

In the case of the flexible flat foot which was originating from neuropathic or structural anatomical problems. There were well-established surgeries ready for the patients, for example, lateral column lengthening described by Evans or minimally invasive arthroereisis. Long-term studies for arthroereisis were rare. The prescription for conservative treatment or surgical options for flexible flat feet must be judged with caution without affecting by the parents (Wagner et al., 2013).

If the complaints by the patients did not resolve and affected their daily lives due to their painful lower limbs, surgical treatment would be an option. Over half of the surgically treated patients were reported as unsatisfactory surgical cases. It was because joint fusion and silicon implantation induces relative other osteoarthritic changes and led to the high unsatisfactory rate. Nevertheless, Achilles tendon contracture patient was strongly advised to perform lengthening and relaxation procedures (Atik & Ozyurek, 2014).

2.2. Evaluation and clinical assessment of flexible flat foot

2.2.1. Static foot print measurement

Foot print assessment was one of the most popular methods to classify different types of Medial Longitudinal Arch (MLA)(Figure 1). It was efficient and cost-effective, and yet, obtained the same effective result as radiologic evaluation (Ebrahim Sadeghi-Demneh et al., 2015a),(Sadeghi-Demneh et al., 2016). Among all, Arch Index (AI) was used in this study to differentiate between flat foot, normal foot, and high arch foot. The AI of each subject was measured by a 3D Laser Full-Foot Scanner – UPOD by ScanPod 3D. With an index more than 3, the subject was considered as flat foot where the normal value between 2.2 to 3 (Singh et al., 2010). During daily clinical practice, the flexibility of the subject would be evaluated after the foot print classification.

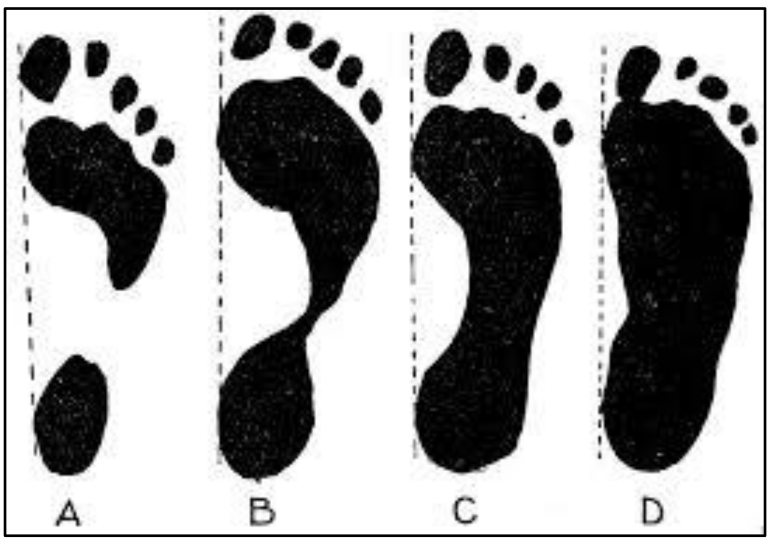


Figure 1 Foot prints of high arch, normal, pronated, and flat from A to D respectively

2.2.2. Arch Index (AI)

Cavanagh and Rodgers developed the Arch Index (AI) for foot arch description. The index could be calculated by first defining the “foot axis”, which was a line passing through the most posterior mid-point at the heel (point k) and the tip of the 2nd toe. A perpendicular line was drawn to the foot axis and tangent to the most protruded point (point j) of the metatarsal head area. With the same tangent line, removing all the prints distally which would be the toes’ prints. A line jk was drawn and divided into 3 equal sessions. These four points along the line jk divided the print into three parts, namely A, B, and C. The AI was a ratio indicating the percentage of area B to the total area of A, B, and C (AI=B/ (A+B+C)). (Figure 2, normal range was 0.21~0.26, lower arch range was AI≥0.26, higher arch range was AI≤0.21) (Cavanagh PR, 1987).

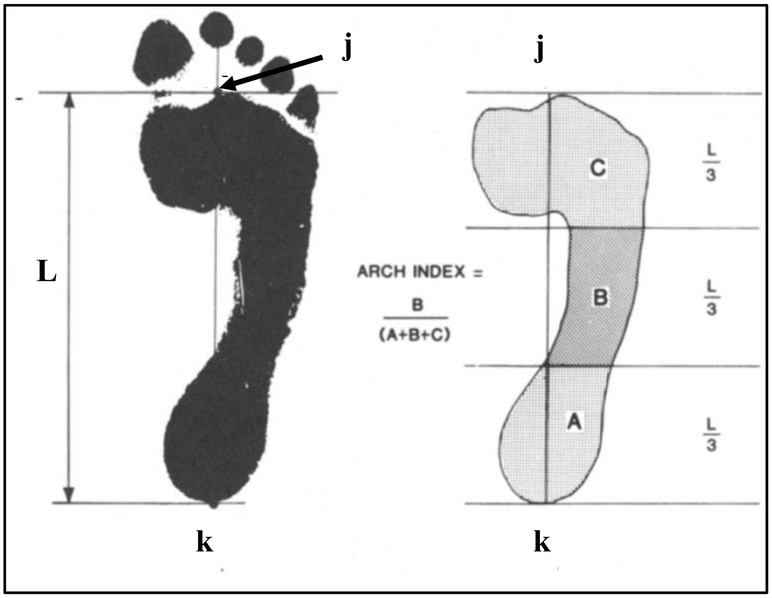


Figure 2 Arch Index (AI) formula demonstration

2.2.3. Valgus Index (VI)

Calcaneal Valgus was a common foot condition as well in the younger aged populations (Figure 3). The index reflected the distance relationships between the mid-point of the heel and the transverse plan projections of two malleoli of the ankle. As shown in Figure 4, VI= [(1/2AB – AC)/AB] x 100 (Points A & B were the vertical projections of the medial and lateral malleoli (Red arrows). Point C was the intersection point of line AB and the line passing through the mid-point of the heel and the 3rd metatarsal head), the VI value below 10.37 referred to low arch condition (Rose GK, 1985).

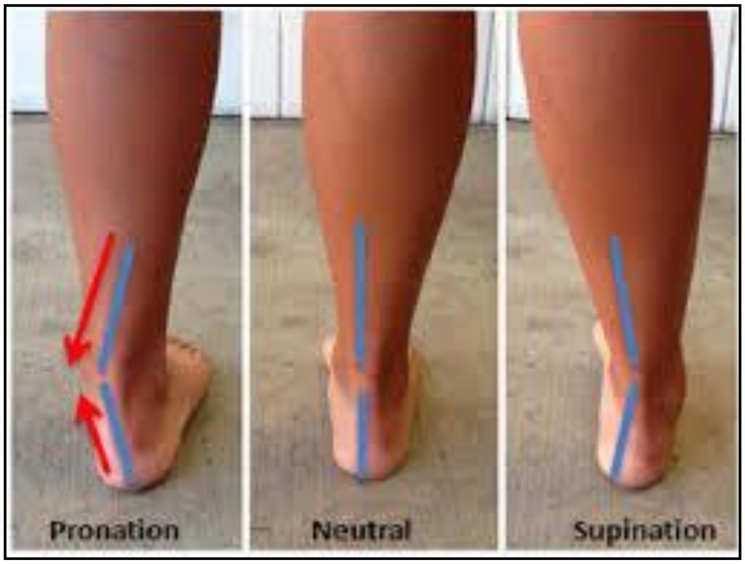


Figure 3 Calcaneal valgus, neutral, and varus positions from left to right respectively

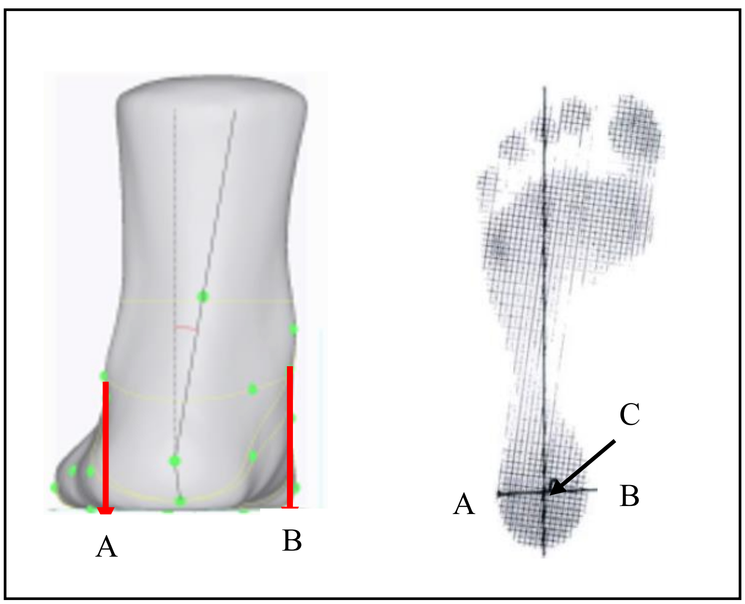


Figure 4 Selected points for calculating Valgus Index (VI)

2.2.4. Medial Arch Height (MAH)

There were several definitions of MAH. One of those was measuring the vertical distance from the ground to the navicular bone insertion point (Shiang TY1, 1998). Traditionally, the MAH was obtained by the clinician through manual measurements. Firstly, by locating the first metatarsal head and the most protruded point of the heel, the arch length (AL) was measured. The arch mid-point was then obtained by dividing the AL by two (Figure 5). The next step was to extend the arch mid-point laterally into the medial arch, which should be parallel to the body's coronal plain (Figure 6). The MAH could be measured by placing a ruler perpendicular to the extended point shown in Figure 7. Finally, the MAH was the intersection point where the skin and the ruler met.

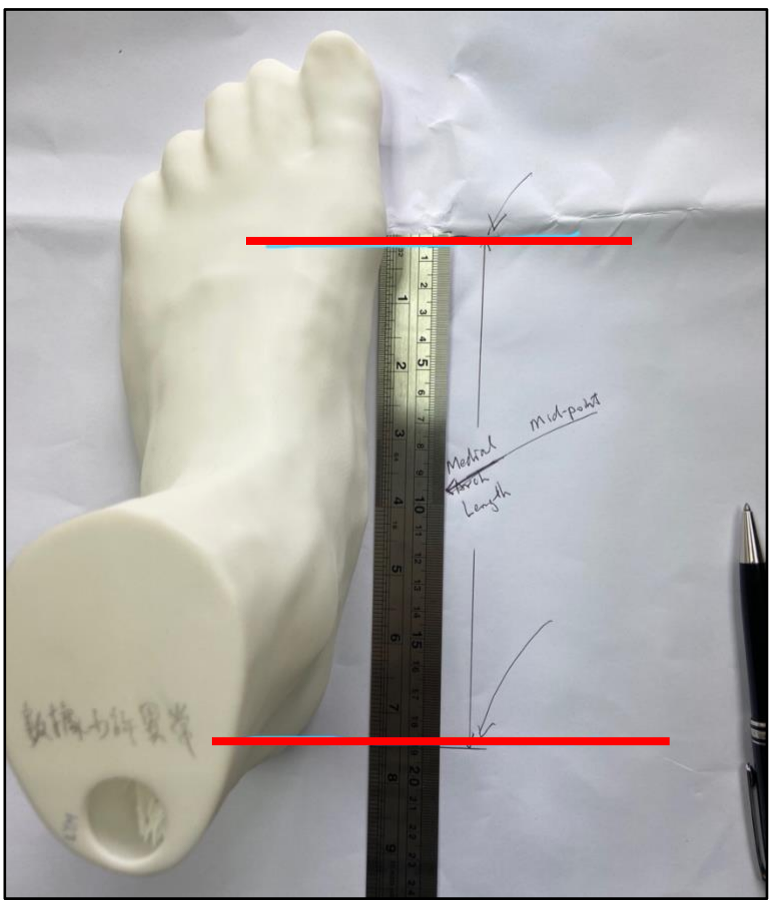


Figure 5 Medial Arch Length midpoint

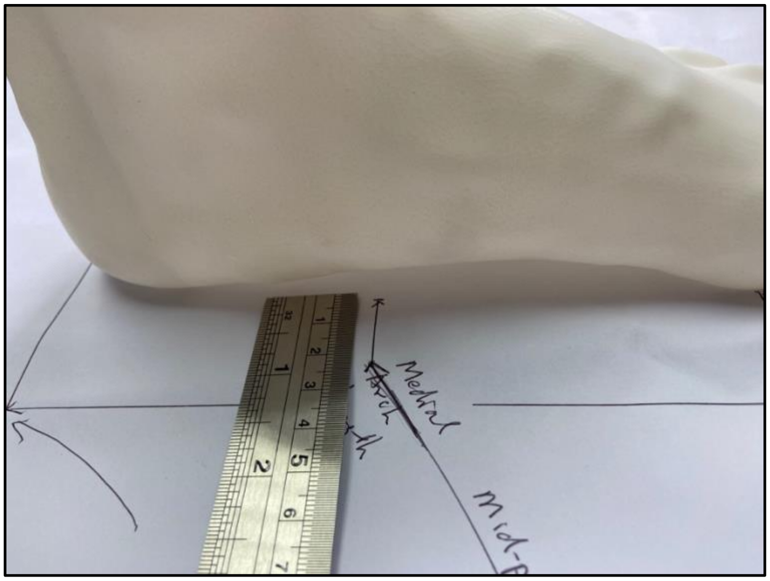


Figure 6 Medial Arch Height measurement point

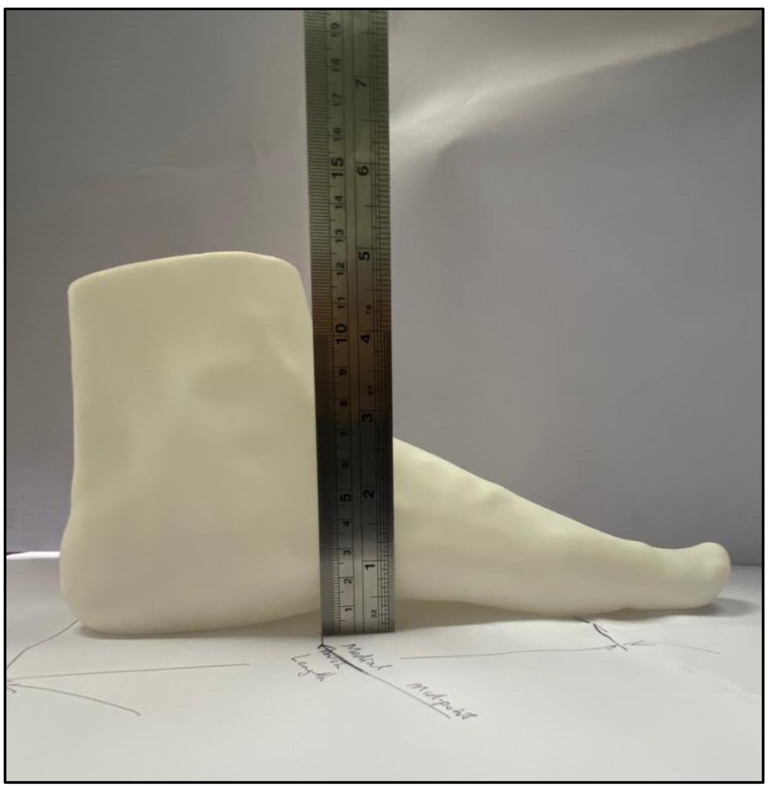


Figure 7 Medial Arch Height value

In this project, the MAH was measured by the UPod scanning device and defined as shown in Figure 8. It measured the vertical distance from the ground to the skin surface where it was the mid-point of the arch (in the red circle).

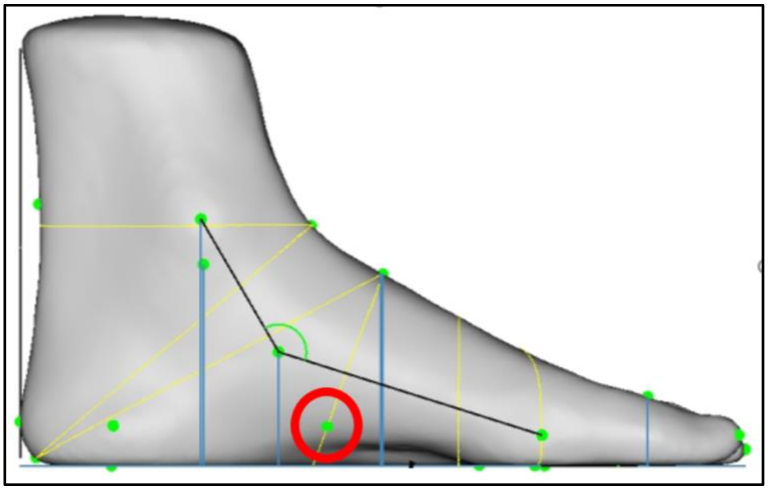


Figure 8 Medial Arch Height location

2.2.5. Arch Length (AL) and Arch Height Ratio (AHR)

The Arch Length (AL) was the distance from the center of the heel to the 2nd Metatarsal Head (the red line in Figure 9). The MAH/AL (AHR) was a ratio between the medial arch height and the arch length (Figure 10). The advantage of using AHR was that this ratio could eliminate the growing factor when comparing arch height among the subjects. The formula of AHR was as follow; AHR= MAH/AL *100 (A. N. Onodera et al., 2008).

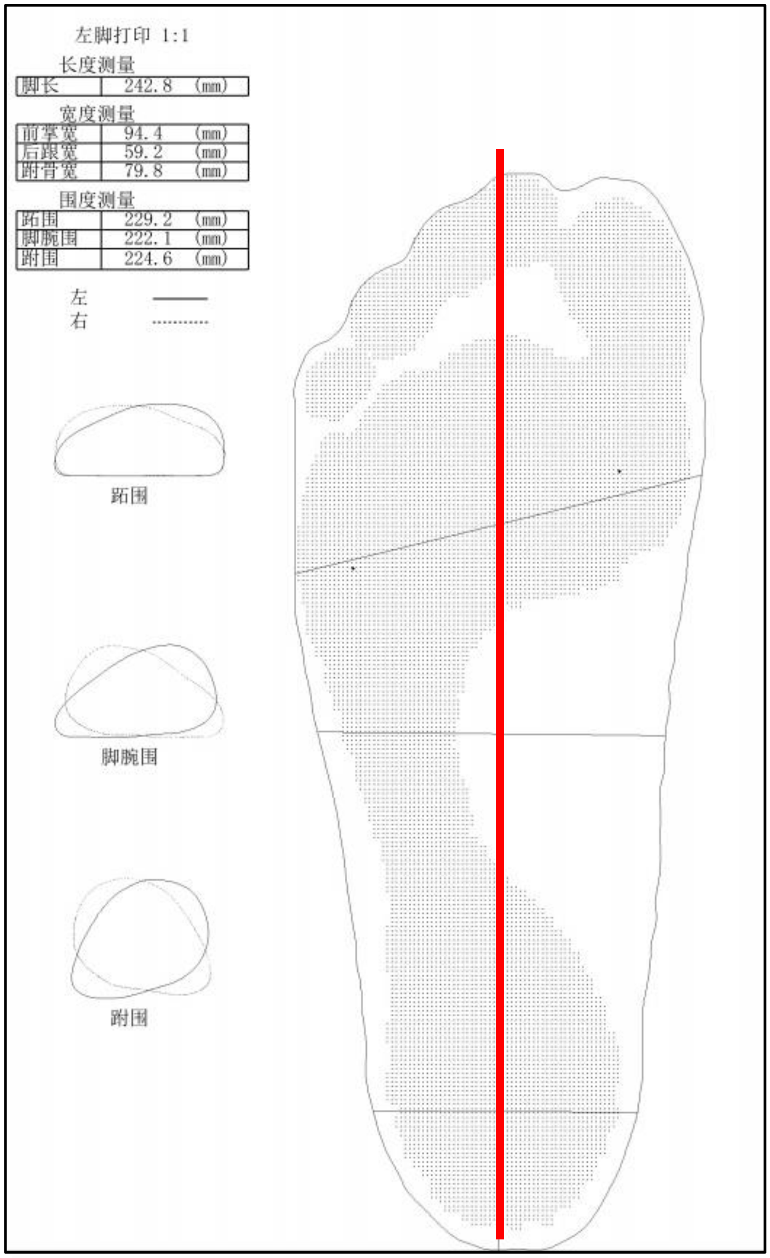


Figure 9 Foot print longitudinal axis (red)

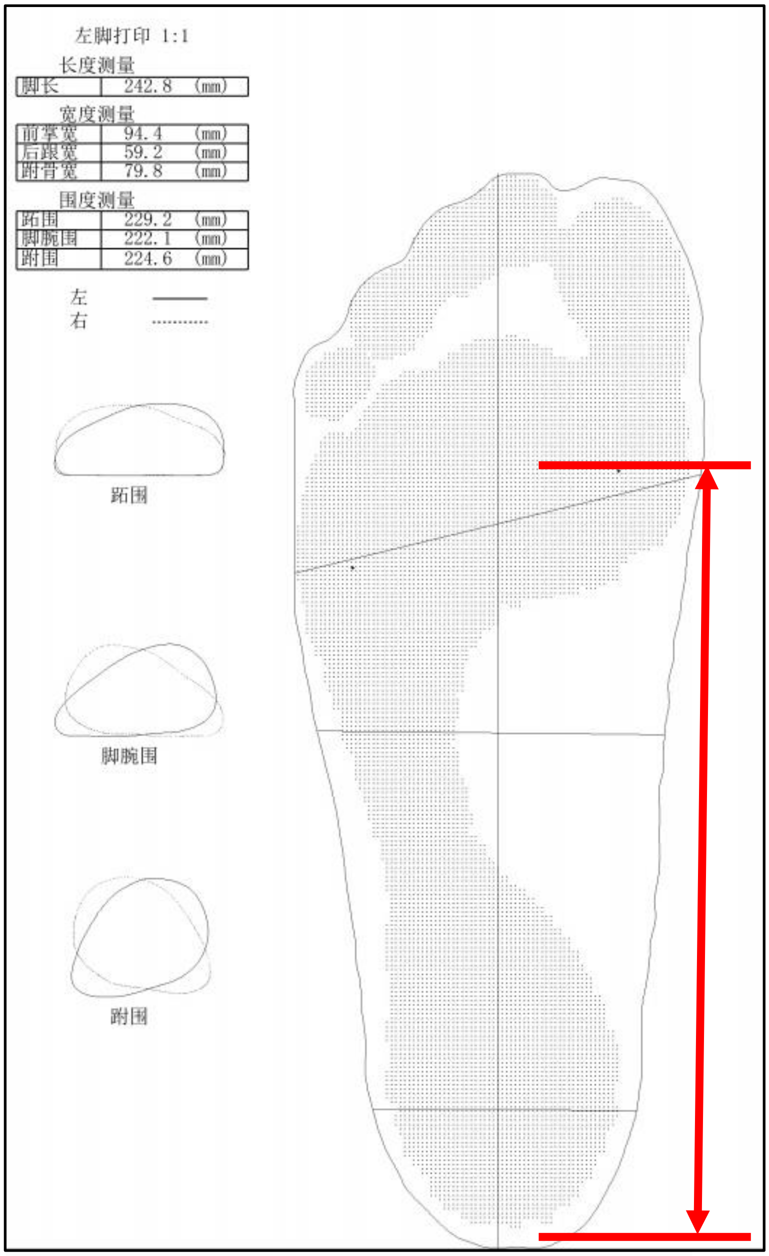


Figure 10 Foot print Arch Length (AL), the red arrow

2.2.6. Clinical assessment

There were several methods to detect the shape of the Medial Longitudinal Arch (MLA). The first method was a subjective assessment, by assessing patients' MLA at weight bearing, non-weight bearing positions, and during walking. This method was also known as a series of clinical observations which required clinicians' experiences and prompted to be more subjective, and relatively lower in reliability (Razeghi M1, 2002). The second method was the radiographic assessment by taking X-ray images and doing measurements on the images. The X-ray images were taken under weight-bearing conditions. However, this process would be harmful to children who were still at rapidly growing ages (D. M. Dare & E. R. Dodwell, 2014). The third method was to differentiate the foot arch shapes by classified foot prints. The foot print reflected some of the foot arch conditions. The prints would show differences while the foot arch structures with different levels of deformations or positions. Some scholars were contributing to the MLA assessments by observing the foot prints, including Cavanagh and Rodgers's Arch Index (Cavanagh PR, 1987), Chipaux-Smirak index (Forriol & Pascual, 1990), Staheli index (Staheli LT, 1997), etc. This method was simple and some studies showed that AI had some degree of correlation with MLA shapes (Chen et al., 2011; Gilmour JC, 2001; Nikolaidou ME, 2006; A. N. Onodera et al., 2008). The last method was foot dimension assessment. Valgus Index (VI) was calculated by projecting ankle bony prominences on the foot print. MLA height and MLA Height /Arch Length created the Arch Height Ratio (AHR). These indexes took relatively longer preparation time and more operation steps to come to some results; nevertheless, the results were more intuitive and easier to be understood. In recent years, as technology advances, foot scanning devices and computerized 3D model reconstructions were getting popular. This advancement transformed the foot dimensions analysis to be a quick and easy task (A. Waseda, Y. Suda, S. Inokuchi, Y. Nishiwaki, & Y. Toyama, 2014). The costs of foot scanning devices were relatively high which might affect the popularity of the device in clinical practice.

Flexibility evaluation of the foot

Firstly, the subject's ligament flexibility was examined manually (Figure 11). Ligament laxity was more commonly seen in younger kids than in adults. This condition was one of the main factors contributing to flexible flat feet in young children. When a child could hyperextend his thumb touching his forearm or hyperextend other fingers parallel to the back of his hand. It was classified as ligament laxity. In addition, genu recurvatum and cubital recurvatum should be present as well in ligament laxity child (Atik & Ozyurek, 2014)

Figure 11 Foot flexibility assessment at clinic

Secondly, the subject performs a tip-toeing position, if the heel was not inverted and the foot arch cannot form accordingly, then the child did not possess flexible flatfoot. Further rigid flat foot deformity would be assessed. The pathology might be due to neurological, and myopathic disorders, painful, and restricted rearfoot movements, calcaneus equinus, or navicular pain (Atik & Ozyurek, 2014)

2.3. Other studies on the relationships between flat foot and commonly known aspects

2.3.1. Relationship between BMI and flat foot

Nowadays, over-weighted individuals were commonly seen in many developed countries and the number was growing for all ages people globally. There was 30% of the kids in Spain were classified as obese. This condition was associated with long-term health concerns. As for the musculoskeletal system, obesity or being overweight was another key factor promoting the acquisition of flatten arches and might lead to discomfort or pain in the lower limb as a result (Jiménez-Ormeño et al., 2013). Chang, Wang, et al reported that the prevalence of flat foot in their study of 2083 Taiwanese kids from age 7 to 12 was 59%. They also found that obese and overweight children were 2.66 times and 1.39 times more cases occurred than average weighted ones (J.-H. Chang et al., 2010).

2.3.2. Relationship between gender and flat foot

In addition to the obesity issue, gender differences in foot morphology changes were another popular topic in western countries. American boys experienced their feet growing at peak at age 13 while it was age 11 for U.S. girls. In Germany, male kids' feet stopped growing at age 15 and it was 13 for the girls in the country. As for Greek society, boys showed a lower arch tendency than girls throughout the ages of 13 to 17 (Xu et al., 2019). Delgado and his team concluded in their study done in Spain that the growth trends of the two sexes were similar in general; however, the differences appeared at the age of 8 and 10 for boys and girls respectively (Delgado-Abellán et al., 2014). These findings were considerably close to those results in previous works in Hong Kong (China), Glasglow (UK), and Germany.

Given the high prevalence of flat feet in the early stage of human life, there were a substantial amount of studies were on this topic. Some of them focused on the foot length growth patterns, some investigated the differences between the two genders in different age ranges. There were more parameters had been analyzed; BMI, foot width, foot circumference, and footprint were examples. However, among those reviewed studies, aiming at the growing pattern of the kid's arch shapes was rare. It would be of interest to understand the foot arches growing pattern which was a relatively less mentioned parameter before. Furthermore, the correlation of this parameter could be examined together with age, and gender forming a foot arches growth pattern for clinical diagnosis. Moreover, there was no large-scale survey on children and adolescents 3D foot data analysis had been conducted. This project addressed the two main issues which have not been done before and were stated in the project objectives.

2.3.3. Relationship between different regions and flat foot

It had been believed that different countries, cities, regions, or areas having different flat foot prevalence. Abich and his team reported in 2020 that Iran, Colombia, Islamabad, Pakistan, and Sri Lanka had an estimated prevalence of flat foot between the ages of 11-15 children was around 14 – 17%, whereas, in those higher socio-economic regions, the prevalence was ranging from 30% to 59% and they were Saudi Arabia, Taiwan, Poland, Vienna, Austria and Nigeria (Abich et al., 2020). The differences shown were on the country level or ethnicity level. Abich reported that the different types of schools showed significant differences as well. There was a higher prevalence of symptomatic flat foot in Private schools than in Government schools. The BMI distributions were significantly varied. They believed that a higher BMI population in Private schools led to higher flat foot occurrence (Abich et al., 2020)

2.3.4. Observation on growth trend and foot maturity

Waseda, et al stated that human feet would have bony structural changes from the children to the adolescent stage in the growing process (Akeo Waseda, Yasunori Suda, Suguru Inokuchi, Yuji Nishiwaki, & Yoshiaki Toyama, 2014). And some researchers found that MLA developed at its fastest stage at the age of six (O. El et al., 2006; E. Sadeghi-Demneh et al., 2015; Volpon, 1994a). The growth after six-year-of-age would be slower and this growing trend was undergoing a certain number of debates. Some studies reported that the MLA remained unchanged from the age of seven to nine (K. Bosch, Gerss, & Rosenbaum, 2010; Muller, Carlsohn, Muller, Baur, & Mayer, 2012).

On the contrary, Onodera and his team found that the MLA continued to grow at this stage (A. N. Onodera et al., 2008). Chen's team reported that the height of MLA would drop at the age of seven and eight, and the height went up again after the ages of studying the kids in Taiwan (J. P. Chen, M. J. Chung, & M. J. Wang, 2009). Pfeiffer and his team observed that the MLA stopped growing at the age of 12 to 13. (M. Pfeiffer, R. Kotz, T. Ledl, G. Hauser, & M. Sluga, 2006). In addition, the growth between the two sexes showed some differences. MLA heights of boys were lower than that of girls. Lower MLA height demonstrated a flattening of the MLA in general (J. P. Chen et al., 2009; J. J. Echarri & F. Forriol, 2003).

Chapter 3 Methodology and procedure

3.1. Subject population and data collection

The subjects were recruited randomly in five areas across China; which were Shanghai (上海),

Guangdong (廣東), Hunan (湖南), Hebei (河北), and Sichuan (四川) dated from October of 2017 to might of 2018. A total of 8974 subjects from ages 6 to 16 were assessed and the full-foot digitized 3D data were recorded. 5218 boys and 3737 girls were from 19 schools (靜安實驗小學、四川北路一小、涼城三小、中山小學、楊東小學、羅南中心小學、保定路一小、曲陽三小、涼城二小、廣中路小學、澄衷初級中學、虹口霍山學校、茶店子小學、金牛中學、長沙市高新區白馬學校、金地小學、石家莊十六中、番禺執信中學、廣州番禺會江實驗學校) joining this project. Provided that all the subjects had no history of injuries or other visible deformities in the lower limbs. This study granted the consent of all the schools involved and the approval of the ethical committee. The foot assessment processes were under the supervision of the schools. All the scanning processes were arranged and finished before noon to minimize the influences of the time effects in different periods in the daytime. Other than collecting the 3D foot model, a questionnaire (Appendix A) was designed and finished by every subject as well. The purpose of the questionnaire was to understand more about the subjects' exercising habits and other body conditions. The China Next Generation Education Foundation 中國下一代教育基金會 and Fu Dan University 復旦大學運動醫學中心 would conduct another investigation with that set of data which was not part of this study.

3.1.1. Data collection position of the subjects

All the data were collected at a standing position of the subjects. They stood upright with both of their hands relaxed and put on each side of their bodies. With straight eyesight, keeping their feet separated at the width of their shoulder width; so that the body weight could be kept balanced on both of their feet.

3.1.2. Data collection devices and procedures

The Valgus Index (VI) was first retrieved with the VALGUS INDEX Podometer (Figure 12), and software (Figure 13a & 13b), which could measure a valgus heel, a varus heel, and a neutral heel, provided by Dr. Kong Footcare Limited. On the glass surface of the device, there were three pairs of straight lines as guidelines for different body height subjects to stand on to control possible standing errors. The three guided lines were namely A (body height below 125cm), B (body height between 125 – 150 cm), and C (body height over 150cm). On each line, the foot must be put over it with the 2nd metatarsal head bone (forefoot ball area) and the most prominent point on the footprint of the calcaneus (heel bone). Figures 13a & 13b demonstrated the VI software user interface when doing the measurement.

After the proper standing position was confirmed, then informing the subject to keep standing still for a few seconds for the photo-taking processes, and two photos were taken on each foot. The measurement of VI was performed on the photo accordingly in the software. Three points had to be put on the foot image over the most prominent point of the medial and lateral malleoli, and the lowest mid-point of the heel. The software could then calculate the results. The VI collection was the first step of the procedures. The second step was to collect the 3D foot data with the 3D foot scanning device (UPOD 3D Laser Full-Foot Scanner 2.5.3, Vismach Technology Ltd, Figure 14). The same positions were required and controlled as standing on the Podometer. The scanning process could then start. The scanning machine calculated and exported the Medial Arch Height

(MAH), Arch Length (AL), Forefoot Width (FW), Forefoot Circumference (FC), Arch Circumference (AC), Girth Circumference (GC), MAH/AL (AHR), Cavanagh and Rodgers Arch Index (AI) (Cavanagh and Rodgers Arch Index, AI) through reconstructing the whole foot 3D digitized model of the scanned feet (Figure 15).

This study deployed automated strategies to retrieve foot anthropometric data and to generate two commonly recognized indexes for analysis. The first one was a 3D foot scanning technology (UPOD 3D Laser Full-Foot Scanner 2.5.3, Vismach Technology Ltd) that was responsible for the Arch Index (AI) generation and dimensional data. The Valgus Index (VI) was calculated by The VALGUS INDEX podometer (Dr. Kong Footcare Limited) to collect. With these advancements, the processes become more accurate and efficient, so that the survey could cover a greater number of subjects with ease.

Figure 12 The outlook of the VI podometer

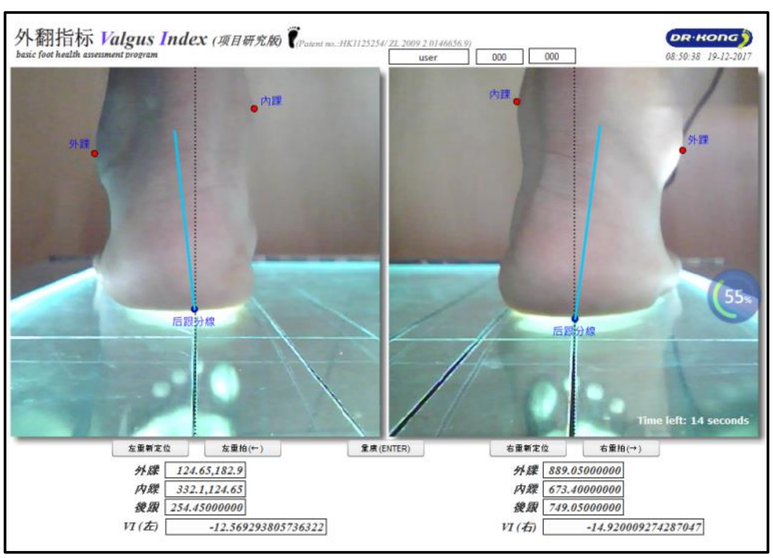


Figure 13a Demonstrated a pair of varus feet

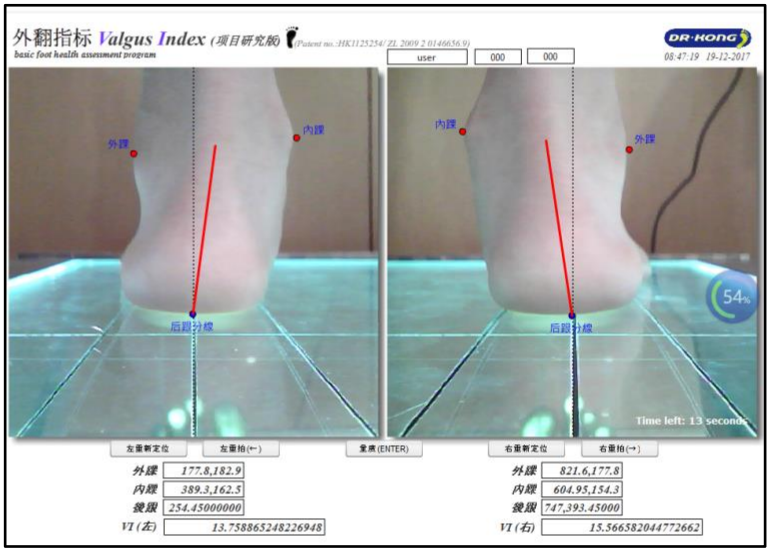


Figure 13b Demonstrated a pair of valgus feet

Figure 14 The outlook of the UPod scanning device

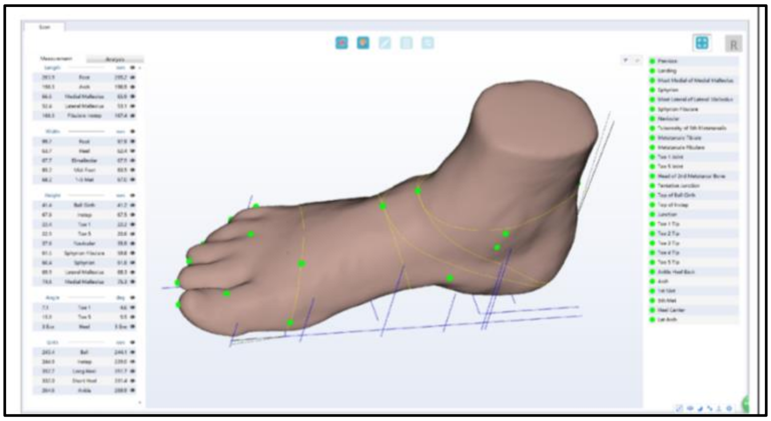


Figure 15 Reports on the data collected from the UPod scanner

3.1.3. Data collection personnel

During the data collection process, two individual investigators, who did not have any communications, conducted the procedures concurrently on the same student in sequence. The average of two sets of data was calculated as the final record. If the data retrieved from the separated researcher were comparatively large, with 3mm differences in the foot length as an example, the process would be restarted. This comparison of the two sets of data aimed to reduce the possible inter-investigator errors. In addition, the devices were calibrated every time before the mass data collection process. Figure 16 showed some data collection works on site.

Figure 16a Data collection processes


Figure 16b Data collection processes

Figure 16c Data collection processes

Figure 16d Data collection processes

Figure 16e Data collection processes

3.2. Data analysis

To understand the growth of children's foot structure, a cohort longitudinal study (the whole growing period) was recommended. Nevertheless, it required relatively huge resources to revisit over a few thousand subjects. A certain amount of dropout rate was predictable as well. Whereas, by conducting a cross-sectional study about foot shapes distribution among different ages in a considerably large subject population, it was believed to be able to obtain a similar result compared to a cohort longitudinal study (A. Waseda et al., 2014). For this reason, this study was regarded as a cohort cross-sectional study.

According to the plan, in order to retrieve the foot shape and the anthropometric data of 8955 kids with efficiency and higher reliability, 3D foot scanning devices were deployed, which were the same brand of devices used in the study in 2010 conducted by Singh and his team (Singh et al., 2010). The device used in this study was UPOD 3D Laser Full-Foot Scanner 2.5.3 which was a product of Vismach Technology Ltd. In addition, VI was another key parameter recorded in this survey. The VALGUS INDEX Podometer by Dr. Kong Footcare Limited was used to obtain the VI values.

3.2.1. Frequency and Descriptive statistic

The investigated data were Arch Index (AI), Valgus Index (VI), body weight, height, foot length, and gender, Medial Arch Height (MAH), Medial Arch Length (MAL), regional data, and pain incidents. Frequency summary for categorial data, which were gender, regions, and pain incidents. The Arch Height Ratio (AHR) was calculated by Medial Arch height (MAH) and Medial Arch length (MAL) for correlation analysis. Descriptive information including AI, VI, body weight, height, foot length, MAH, and MAL was integrated to determine the growth trend of the kids from ages 6 to 16. The dominant limb data was chosen to ensure statistical independence (M. S. Park et al., 2010)

3.2.2. Correlation among parameters

The AI, VI, AHR, Regions, BMI, gender, and pain incidents displayed a non-normality distribution of data. Correlation analysis with Spearman's rho was performed. The correlation of flat foot and valgus foot to Different regions of China, Gender, and Pain occurrence were interested to many investigators. As for the regional data, it was especially unknown to the academic world. There was no China regional data study has been done, at least up to the author's knowledge. This study tried to accompany a large population of data to try to figure out the strength level of the described relationships above.

Regression analysis

Regression analysis was done to generate an easily accessible equation for daily clinical use. AHR was the relationship between medial arch length and arch height, in which the 2 parameters could be retrieved by a ruler, with no extra sophisticated device required (refer to session 2.2.4 for measurement details). On the other hand, VI was a commonly accepted index to classify arch types. At the same time, these two parameters showed the highest correlations among the data set. Therefore, they were chosen to form the described equation above, which could be useful for easier arch-type classification for clinic practitioners.

3.2.3. Growth trend analysis

The collected data were processed by SPSS Statistics 26. The means and standard deviations were calculated according to different ages, genders, and all other parameters. Under the grouping of the same sex, the variances of each parameter were generated as well. With these variances, the Bonferroni test was deployed to compare the two groups. Within the same age, Independent T-test was used to compare the parameters' means between the two genders. The significance was set at $p < 0.05$. The correlation between AI and VI was also studied at different ages. After discovering the growing trend of kids. A reference guideline could be suggested for the treatment of flexible flat feet of the young populations.

Chapter 4 Results

4.1. Frequency and descriptive statistics

In this study, 8955 subjects aged from 6 -16 in the ratio of 5218 or 58.3% male and 3737 or 41.7% female subjects were measured. Table 1 showed the gender distribution and the corresponding percentages of the two genders. Table 2 was about the subject populations at different ages and the corresponding percentages. Table 3 shows the number of participants of different ages, the mean body heights and weights, and the percentage of male subjects. All the statistical analyses were done by SPSS Statistics 26. The significance level was set at p <0.05.

Table 1 Gender distribution

Gender

	N	%
Male	5218	58.3
Female	3737	41.7
Total	8955	100.0

Table 2 Subject population at different ages

Age	N	%
6	131	1.5
7	948	10.6
8	1388	15.5
9	1190	13.3
10	1483	16.6
11	1225	13.7
12	867	9.7
13	733	8.2
14	623	7.0
15	291	3.2
16	76	.8
Total	8955	100.0

Table 3 Ages, No. of Subjects, male %, means and standard deviations of body heights and weights

Age	No. of Subjects	Male %	Height (cm)	Weight (kg)
6	131	45.45%	123.49±0.65	23.99±0.46
7	948	55.79%	125.51±0.20	25.41±0.18
8	1388	60.03%	129.95±0.20	27.94±0.19
9	1190	64.83%	136.35±0.87	31.38±0.22
10	1483	60.16%	142.23±0.20	36.11±0.24
11	1225	54.69%	147.93±0.24	40.27±0.29
12	867	55.37%	153.69±0.30	44.94±0.38
13	733	54.83%	158.77±0.30	48.92±0.42

14	623	57.74%	162.20±0.34	52.61±0.46
15	291	54.45%	164.01±0.43	53.84±0.65
16	76	63.16%	166.12±1.09	53.24±1.10

Table 4 Subject distribution in Five Regions

Five Regions

	N	%
Mid_East	3596	40.2
Middle	624	7.0
North	836	9.3
South	3075	34.3
West	824	9.2
Total	8955	100.0

Table 5 Pain occurrence

Foot Pain

	N	%
Pain	4827	53.9
No Pain	4128	46.1
Total	8955	100.0

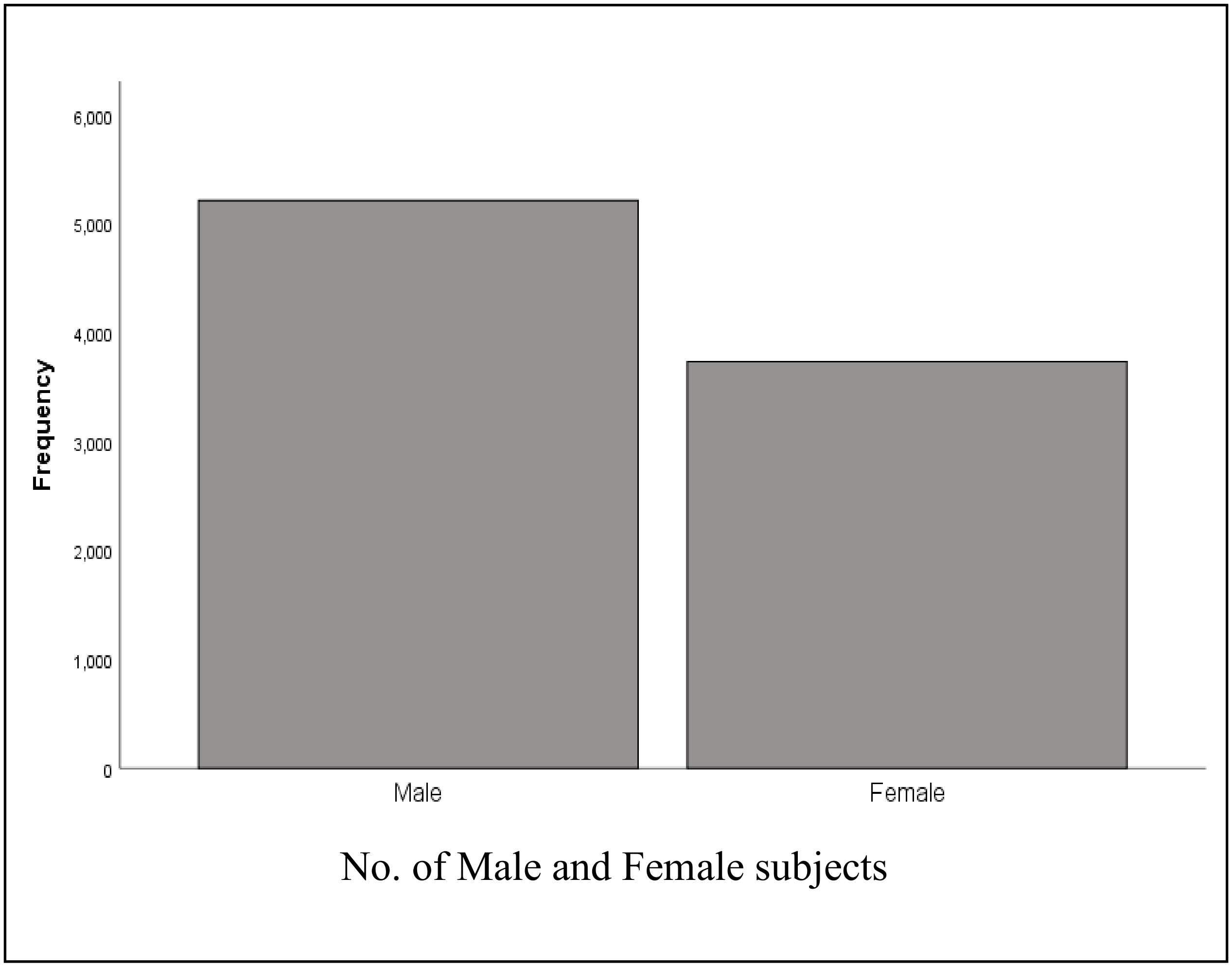


Figure 17 Gender distribution

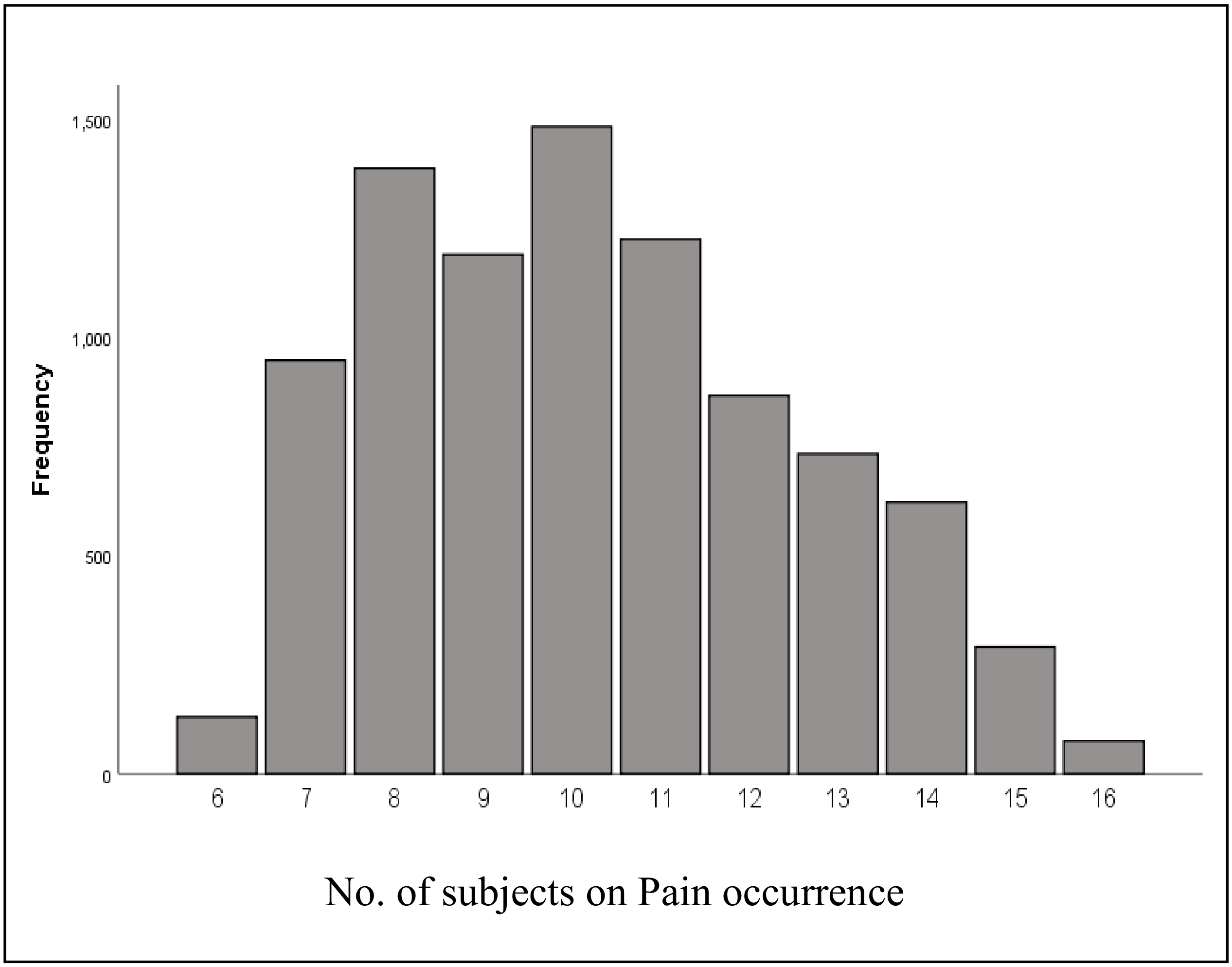
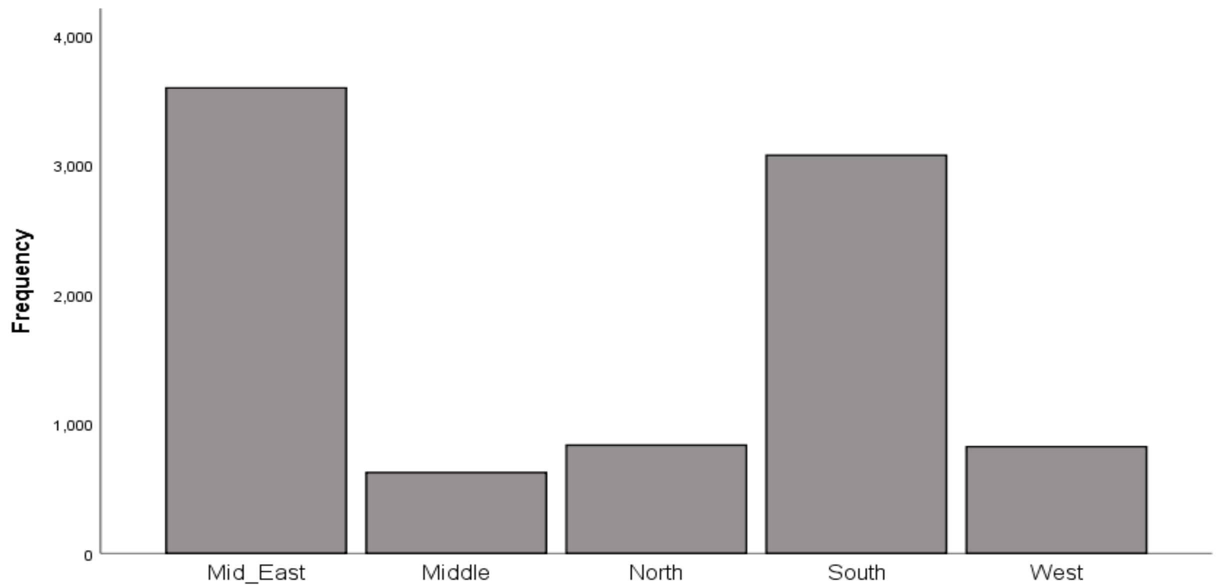
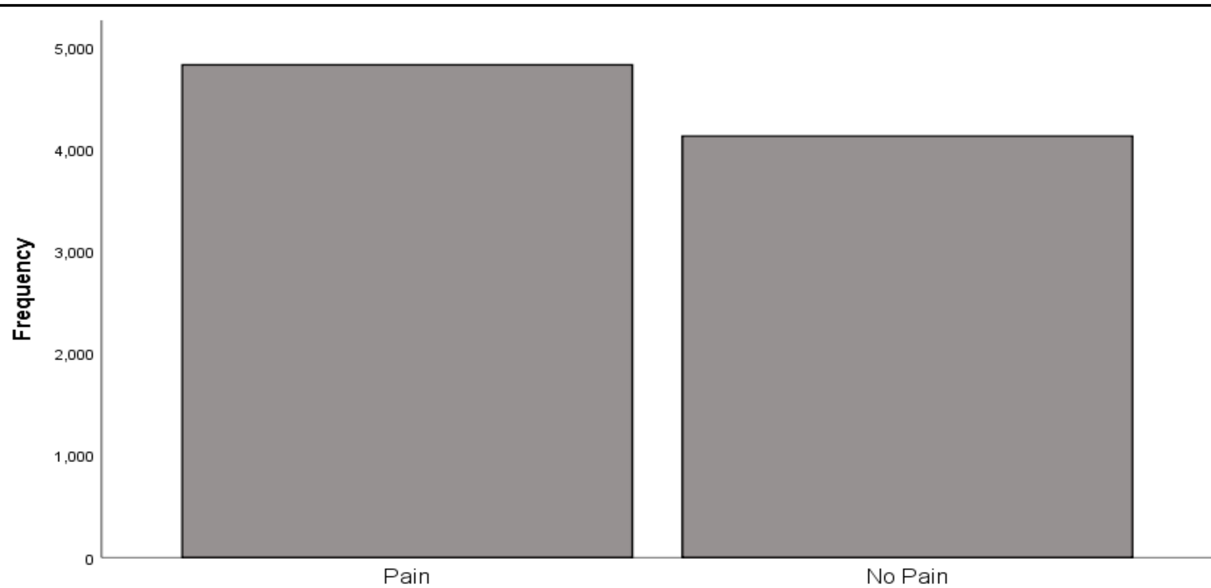


Figure 18 Subject population at different ages



No. of subjects in Five Regions

Figure 19 Subject population in Five Regions



No. of subjects on Pain occurrence

Figure 20 Pain occurrence

Table 6 Descriptive statistics of major parameters

Descriptive Statistics

	N	Mean	Std. Deviation
Valgus Index	8955	9.72	4.88
Arch Index by area %	8955	.26	.05
Medial Arch Height	8955	5.12	3.32
Foot Length	8955	217.12	20.65
MAH FL ratio	8955	2.33	1.45
Arch Length	8955	156.32	14.85
Arch Height Ratio	8955	3.23	2.02
Body height	8955	142.92	14.39
Body weight	8955	37.23	12.81
Body Mass Index	8955	17.77	3.79
Valid N	8955		

In table 7, it showed all the correlations of the listed parameters. The double asterisk mark means that the correlation was significant at the 0.01 level, and the single asterisk mark means that the correlation was significant at the 0.05 level. More than half of the parameters were statistically significantly correlated. The correlation would be presented one by one in later passages. The correlation between AI and AHR would be first investigated.

Table 7 Correlations among VI, AI, AHR, Five Regions, BMI, Age, Gender, Foot pain

Correlations

			Valgus Index	Arch Index by area %	AHR ratio	Five Regions	Body Mass Index	Age	Gender	Foot_Pain
Spearman's rho	Valgus Index	Correlation Coefficient	1.000	.294**	-.575**	-.048**	-.227**	-.364**	-.123**	-.001
		Sig. (2-tailed)	.	.000	.000	.000	.000	.000	.000	.959
		N	8955	8955	8955	8955	8955	8955	8955	8955
	Arch Index by area %	Correlation Coefficient	.294**	1.000	-.740**	.019	.001	-.294**	-.213**	-.017
		Sig. (2-tailed)	.000	.	.000	.073	.890	.000	.000	.108
		N	8955	8955	8955	8955	8955	8955	8955	8955
	AHR	Correlation Coefficient	-.575**	-.740**	1.000	.004	.094**	.306**	.075**	.026*
		Sig. (2-tailed)	.000	.000	.	.729	.000	.000	.000	.014
		N	8955	8955	8955	8955	8955	8955	8955	8955
	Five Regions	Correlation Coefficient	-.048**	.019	.004	1.000	-.051**	.120**	-.061**	.183**
		Sig. (2-tailed)	.000	.073	.729	.	.000	.000	.000	.000
		N	8955	8955	8955	8955	8955	8955	8955	8955
	Body Mass Index	Correlation Coefficient	-.227**	.001	.094**	-.051**	1.000	.393**	-.049**	.027*
		Sig. (2-tailed)	.000	.890	.000	.000	.	.000	.000	.010
		N	8955	8955	8955	8955	8955	8955	8955	8955
	Age	Correlation Coefficient	-.364**	-.294**	.306**	.120**	.393**	1.000	.019	.126**
		Sig. (2-tailed)	.000	.000	.000	.000	.000	.	.067	.000
		N	8955	8955	8955	8955	8955	8955	8955	8955
	Gender	Correlation Coefficient	-.123**	-.213**	.075**	-.061**	-.049**	.019	1.000	-.069**
		Sig. (2-tailed)	.000	.000	.000	.000	.000	.067	.	.000
		N	8955	8955	8955	8955	8955	8955	8955	8955
	Foot Pain	Correlation Coefficient	-.001	-.017	.026*	.183**	.027*	.126**	-.069**	1.000
		Sig. (2-tailed)	.959	.108	.014	.000	.010	.000	.000	.
		N	8955	8955	8955	8955	8955	8955	8955	8955

**. Correlation significance level at the 0.01 (2-tailed).

*. Correlation significance level at the 0.05 (2-tailed).

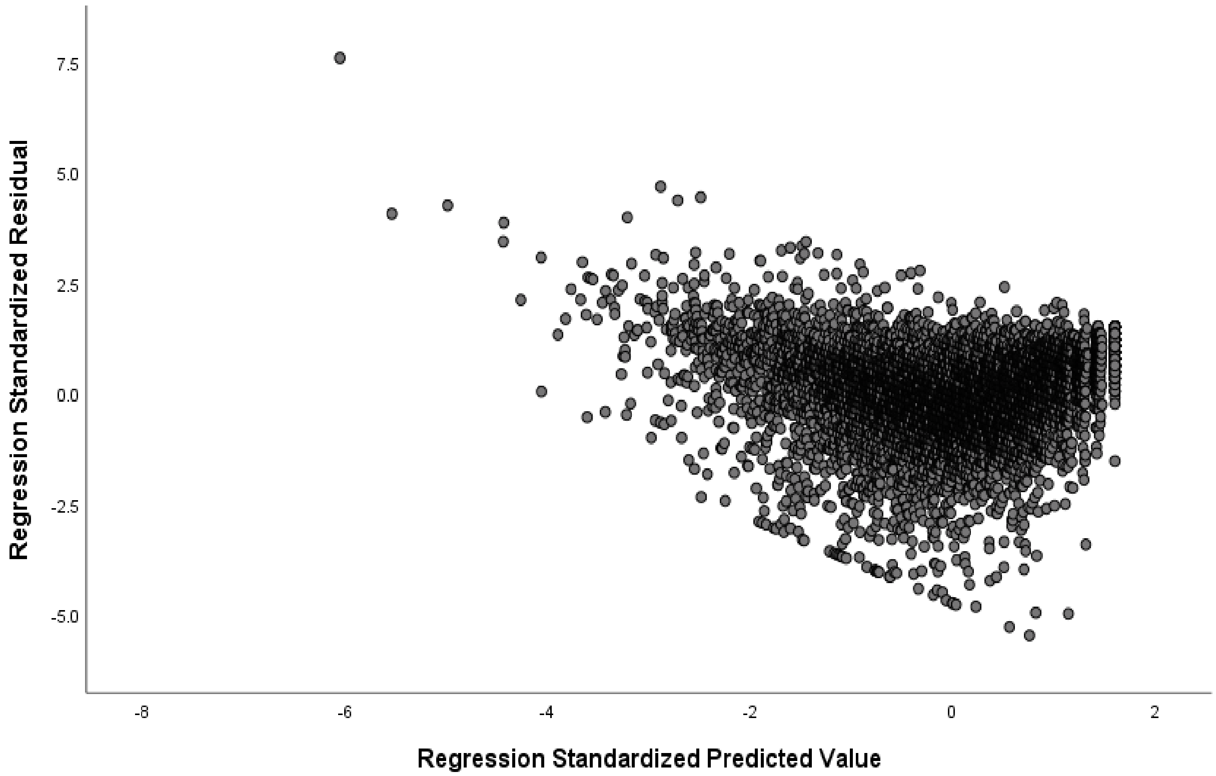
4.2. Correlation among parameters

4.2.1. Correlation of Arch Index (AI) and Arch Height Ratio (AHR)

A Spearman's rho correlation coefficient as computed to assess the relationship between the level of AI and AHR. There was a strong, negative correlation between the two variables, $r = -.740$, $N = 8955$; the relationship was significant ($p = 0.00$). The value of AI appeared to be associated with the value of AHR.

4.2.2. Regression of Arch Index (AI) and Arch Height Ratio (AHR)

A bivariate regression was conducted to examine how well AHR could predict the AI value. A scatterplot and linearity plot, Figure 21, and Figure 22 respectively, showed that the relationship between AHR and AI was negative and linear and revealed mild outliers, which presences were reasonable and acceptable. From Table 8, the correlation between AI and AHR was statistically significant, $r(198) = -.740$, $p < 0.01$. The regression equation for predicting the AI from AHR was $\acute{y} = 0.318 - 0.17x$. The r^2 for this equation was .483; that was, 48.3% of the variance in AI was predictable of the level of AHR. This was a moderate strong relationship (Cohen, 1988).



Linearity Plot between Arch Index (AI) and MAH/AL (AHR)

Figure 21 Scatterplot of AI and AHR

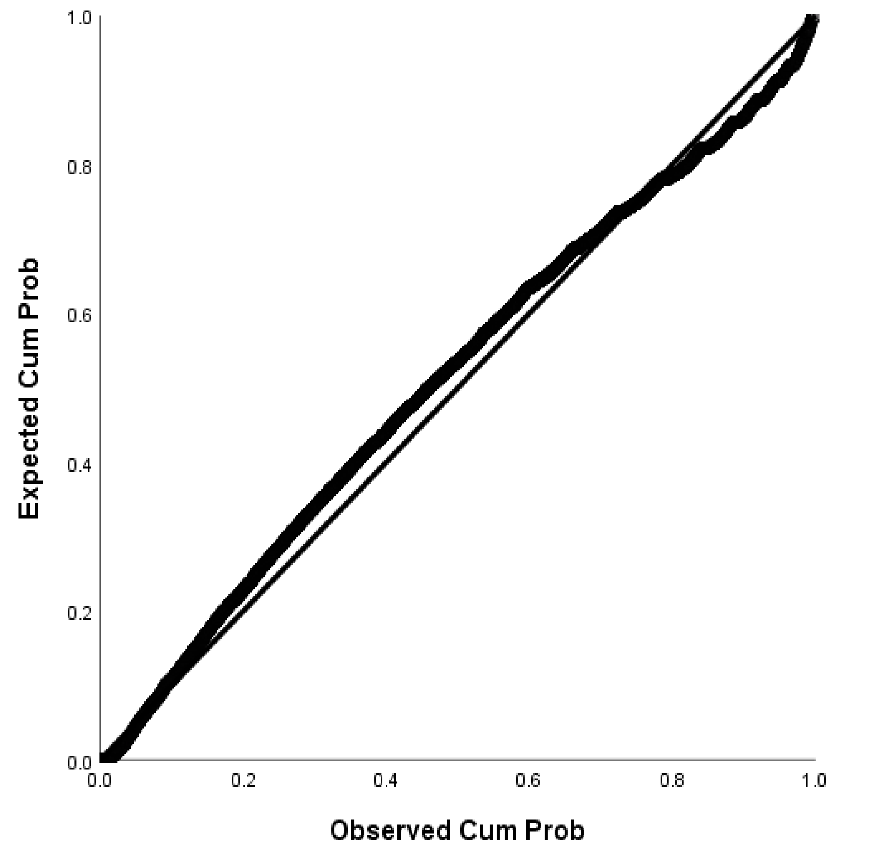


Figure 22 Linearity Plot between AI and AHR

Table 8 Regression Coefficients between AI and AHR

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
	B	Std. Error	Beta			Lower Bound	Upper Bound
1 (Constant)	.318	.001		460.155	.000	.317	.319
AHR	-.017	.000	-.695	-91.368	.000	-.017	-.016

a. Dependent Variable: Arch Index by area %

4.2.3. Correlation of Arch Index (AI) and Valgus Index (VI)

A Spearman's rho correlation coefficient as computed to assess the relationship between the level of AI and VI. There was a weak, positive correlation between the two variables, r = .294, N = 8955; the relationship was significant (p = 0.00). The value of AI appeared to be associated to the value of VI.

4.2.4. Correlation of Arch Index (AI) and Five Regions

A Spearman's rho correlation coefficient as computed to assess the relationship between the level of AI and Five Regions. There was a very weak, positive correlation between the two variables, r = .019, N = 8955; however, the relationship was not significant (p = 0.73). The value of AI did not appear to be associated to Five Regions.

4.2.5. Correlation of Arch Index (AI) and BMI

A Spearman's rho correlation coefficient as computed to assess the relationship between the level of AI and BMI. There was almost no correlation between the two variables, r = .001, N = 8955; however, the relationship was not significant (p = 0.89). The value of AI did not appear to be associated to BMI.

4.2.6. Correlation of Arch Index (AI) and Age

A Spearman's rho correlation coefficient as computed to assess the relationship between the level of AI and Age. There was a weak, negative correlation between the two variables, r = -.294, N = 8955; the relationship was significant (p = 0.00). The value of AI appeared to be associated to the value of Age.

4.2.7. Correlation of Arch Index (AI) and Gender

A Spearman's rho correlation coefficient as computed to assess the relationship between the level of AI and Gender. There was a weak, negative correlation between the two variables, r = -.213, N = 8955; the relationship was significant (p = 0.00). The value of AI appeared to be associated to Gender.

4.2.8. Correlation of Arch Index (AI) and Pain occurrence

A Spearman's rho correlation coefficient as computed to assess the relationship between the level of AI and Pain occurrence. There was a very weak, negative correlation between the two variables, r = -.017, N = 8955; the relationship was significant (p = 0.108). The value of AI did not appear to be associated to Pain occurrence.

4.2.9. Correlation of Valgus Index (VI) and Five Regions

A Spearman's rho correlation coefficient as computed to assess the relationship between the level of VI and Five Regions. There was a very weak, negative correlation between the two variables, r = -.048, N = 8955; the relationship was significant (p = 0.00). The value of VI appeared to be barely associated to Five Regions.

4.2.10. Correlation of Valgus Index (VI) and BMI

A Spearman's rho correlation coefficient as computed to assess the relationship between the level of VI and BMI. There was a weak, negative correlation between the two variables, r = -.227, N = 8955; the relationship was significant (p = 0.00). The value of VI appeared to be associated to the value of BMI.

4.2.11. Correlation of Valgus Index (VI) and Age

A Spearman's rho correlation coefficient as computed to assess the relationship between the level of VI and Age. There was a moderate, negative correlation between the two variables, r = -.364, N = 8955; the relationship was significant (p = 0.00). The value of VI appeared to be associated to the Age.

4.2.12. Correlation of Valgus Index (VI) and Gender

A Spearman's rho correlation coefficient as computed to assess the relationship between the level of VI and Gender. There was a weak, negative correlation between the two variables, r = -.123, N = 8955; the relationship was significant (p = 0.00). The value of VI appeared to be associated to Gender.

4.2.13. Correlation of Valgus Index (VI) and Pain occurrence

A Spearman's rho correlation coefficient as computed to assess the relationship between the level of VI and Pain occurrence. There was almost no correlation between the two variables, r = -.001, N = 8955; however, the relationship was not significant (p = 0.959). The value of VI did not appear to be associated to Pain occurrence.

4.2.14. Correlation of Arch Height Ratio (AHR) and Five Regions

A Spearman's rho correlation coefficient as computed to assess the relationship between the level of VI and Five Regions. There was a very weak, negative correlation between the two variables, r = -.048, N = 8955; the relationship was significant (p = 0.00). The value of VI appeared to be barely associated to Five Regions.

4.2.15. Correlation of Arch Height Ratio (AHR) and BMI

A Spearman's rho correlation coefficient as computed to assess the relationship between the level of AHR and BMI. There was a very weak, positive correlation between the two variables, r = .094, N = 8955; the relationship was significant (p = 0.00). The value of AHR appeared to be barely associated to BMI.

4.2.16. Correlation of Arch Height Ratio (AHR) and Age

A Spearman's rho correlation coefficient as computed to assess the relationship between the level of AHR and Age. There was a moderate, positive correlation between the two variables, r = .306, N = 8955; the relationship was significant (p = 0.00). The value of AHR appeared to be barely associated to Age.

4.2.17. Correlation of Arch Height Ratio (AHR) and Gender

A Spearman's rho correlation coefficient as computed to assess the relationship between the level of AHR and Gender. There was a very weak, positive correlation between the two variables, r = .075, N = 8955; the relationship was significant (p = 0.00). The value of AHR appeared to be barely associated to Gender.

4.2.18. Correlation of Arch Height Ratio (AHR) and Pain occurrence

A Spearman's rho correlation coefficient as computed to assess the relationship between the level of AHR and Pain occurrence. There was a very weak, positive correlation between the two variables, r = .026, N = 8955; the relationship was significant (p = 0.014). The value of AHR appeared to be barely associated to Pain occurrence.

4.3. Growth trend

Tables 8a & 8b demonstrated the means and standard deviations of the four parameters for boys and girls respectively, which were Medial Arch Height (MAH), Arch Length (AL), MAH/AL (AHR), and Arch Index (AI). Table 2c presented the mean differences between the two sexes on the four parameters. Figure 23(a, b, c & d) were the graphs explaining the growing trends of the MAH, AL, AHR, and AI along the ages.

From Table 2a and Figure 23a, as the age got older, the MAH of girls rose gradually. The MAH met its platform at age 12 (6.67mm @age 12 vs 7.61mm @age 16, p＞0.05), see Figure 23a； AL grew longer, the length didn't extend at age 12, see Figure 23b (165.21mm @age 12 vs 166.71mm @age 16, p＞0.05)； AHR increased up to age 12 (40.51 @age 12 vs 45.52 @age 16, p＞0.05); AI decreased until age 11(0.24 @age 11 vs 0.23 @age 16, p＞0.05).

Table 8a Changes of the 4 parameters in different ages in girls

7	6	7	8	9	10	11	12	13	14	15	16	Total
Total No. of Kids	132	959	1396	1197	1486	1236	838	735	627	292	76	8955
Total No. of Girls	72	424	558	421	591	560	374	332	265	133	28	3737
MAH means (mm)	3.58	3.52	3.99	4.61	5.12	5.52	6.67	7.05	6.94	6.82	7.61	
SD	0.27	0.12	0.11	0.13	0.12	0.14	0.17	0.19	0.20	0.30	0.65	
AL means (mm)	133.50	137.54	140.10	146.81	156.53	159.55	165.21	166.60	168.53	166.74	166.71	
SD	2.10	0.67	0.60	0.90	0.36	0.79	0.63	0.85	0.51	0.74	1.82	
MAH/AL (AHR) Means	26.84	25.69	28.52	31.60	32.73	34.60	40.51	42.40	41.29	41.19	45.52	
SD	1.96	0.85	0.78	0.87	0.78	0.83	1.04	1.11	1.18	1.84	3.83	
AI means	0.28	0.28	0.26	0.25	0.25	0.24	0.24	0.23	0.23	0.24	0.23	
SD	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	

As for male subjects, Table 8b and Figure 23a indicated that as age increased, the MAH showed little changes at age 13 (6.91 @age 13 vs 8.25 @age 16, p＞0.05); AL grew longer and met its platform at age 13 (173.97mm @age 13 vs 181.03mm @age 16, p＞0.05); AHR stopped rising at age 13, see Figure 23c (39.88 @age13 vs 45.72 @age16, p＞0.05) AI diminished until age 11, see Figure 23d (0.26 @ age 11 vs 0.25@ age16,p＞0.05).

Table 8b Changes of the 4 parameters in different ages in boys

Ages	6	7	8	9	10	11	12	13	14	15	16	Total
Total No. of Kids	132	959	1396	1197	1486	1236	838	735	627	292	76	8955
Total No. of Boys	60	535	838	776	895	676	464	403	362	159	48	5218
MAH means (mm)	2.82	2.96	3.49	4.26	4.73	5.21	6.34	6.91	7.36	7.91	8.25	
SD	0.29	0.11	0.09	0.11	0.10	0.11	0.15	0.17	0.21	0.29	0.59	
AL means (mm)	136.44	137.79	143.37	149.97	156.20	161.59	168.89	173.97	175.16	177.66	181.03	
SD	1.31	0.81	0.47	0.42	0.43	0.65	0.47	0.51	1.10	1.32	1.09	
MAH/AL (AHR) means	20.89	21.53	24.35	28.40	30.32	32.35	37.50	39.88	42.24	44.62	45.72	
SD	2.18	0.80	0.60	0.73	0.66	0.67	0.91	1.01	1.21	1.62	3.24	
AI means	0.30	0.29	0.29	0.28	0.27	0.26	0.26	0.26	0.25	0.25	0.25	
SD	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	

When considering the means differences, from Table 8c and Figure 23, the female subjects' MAH means were significantly higher than male subjects at the age of 6, which was 0.77±0.40 mm. The means discrepancy between the two sexes decreased as the age going up. The mean MAH of boys was significantly larger than that of girls at the age of 15 (Girl 6.82±0.44mm vs boy 7.91±0.29mm, p=0.01). Females' mean AL was shorter than that of males generally. The mean AL was not obvious at the age range of 6-10. From age 11, the mean AL of boys was longer than that of girls and this variance got bigger as the age going up. At the age range of 6-12, the ratio of AHR of girls was larger than boys significantly. But this gap got smaller and smaller, and finally, this difference tended to be statistically insignificant at the age of 13. AI means of girls was smaller than that of boys. Between the age range of 7-14, the mean AI discrepancy kept at 0.02 steadily. At the age of

15, statistically significant could not be found on AI mean. The Mean differences of all the parameters were calculated as girls' values minus boys' values.

Table 8c Variance between boys and girls in different ages of each parameter

Ages	6	7	8	9	10	11	12	13	14	15	16	Total
No. of Kids	132	959	1396	1197	1486	1236	838	735	627	292	76	8955
No. of Boys	60	535	838	776	895	676	464	403	362	159	48	5218
No. of Girls	72	424	558	421	591	560	374	332	265	133	28	3737
MAH diff. (mm)	0.77	0.56*	0.51*	0.35*	0.39*	0.30	0.34	0.14	-0.42	-1.08*	-0.64	
SD	0.40	0.16	0.14	0.18	0.16	0.17	0.23	0.26	0.30	0.41	0.91	
P value	0.057	0.001	0	0.048	0.016	0.079	0.144	0.586	0.161	0.01	0.484	
AL diff. (mm)	-2.94	-0.25	-3.27*	-3.16*	0.33	-2.05*	-3.68*	-7.37*	-6.64*	-10.92*	-14.32*	
SD	2.59	1.09	0.75	0.88	0.61	1.01	0.77	0.96	1.36	1.60	1.99	
P value	0.259	0.820	0	0	0.592	0.044	0	0	0	0	0	
MAH/AL (AHR)	5.94*	4.16*	4.17*	3.20*	2.40*	2.25*	3.00*	2.52	-0.95	-3.43	-0.20	
SD	2.93	1.17	0.97	1.17	1.02	1.06	1.37	1.51	1.73	2.44	5.16	
P	0.044	0	0	0.007	0.019	0.034	0.029	0.095	0.582	0.161	0.969	
AI[a]	-0.03*	-0.02*	-0.02*	-0.02*	-0.02*	-0.02*	-0.02*	-0.02*	-0.02*	-0.01	-0.01	
SD	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	
P	0.003	0	0	0	0	0	0	0	0	0.052	0.233	

Figure 23a was the MAH growth trend versus ages. Two dotted lines were at the age of 11 and 15. The pivoting point was at age 13. There was an obvious diversification of MAH value in males and females at age 14. The divergence was getting wider as the age going up. Between the age of 6 and 12, girls' MAH was higher than boys' MAH which was plotted in Figure 23a. A dense dotted line was at the age of 15 where boys' MAH was larger than that of girls. Figure 23c demonstrated the AHR trend. As for AI, starting from the age of 6 to 16, boys' AI values were higher than that of girls (Figure 23d). It showed the AI trend at different ages. The age of 15 was indicated with a dotted line. It was because, from that age onwards, there were no significant differences between boys and girls on AI.

To summarize, girls' feet slowed down in development at 12, whereas it happened at age 13 for the boy. It implied that the arch formation getting mature at the stated ages respectively.

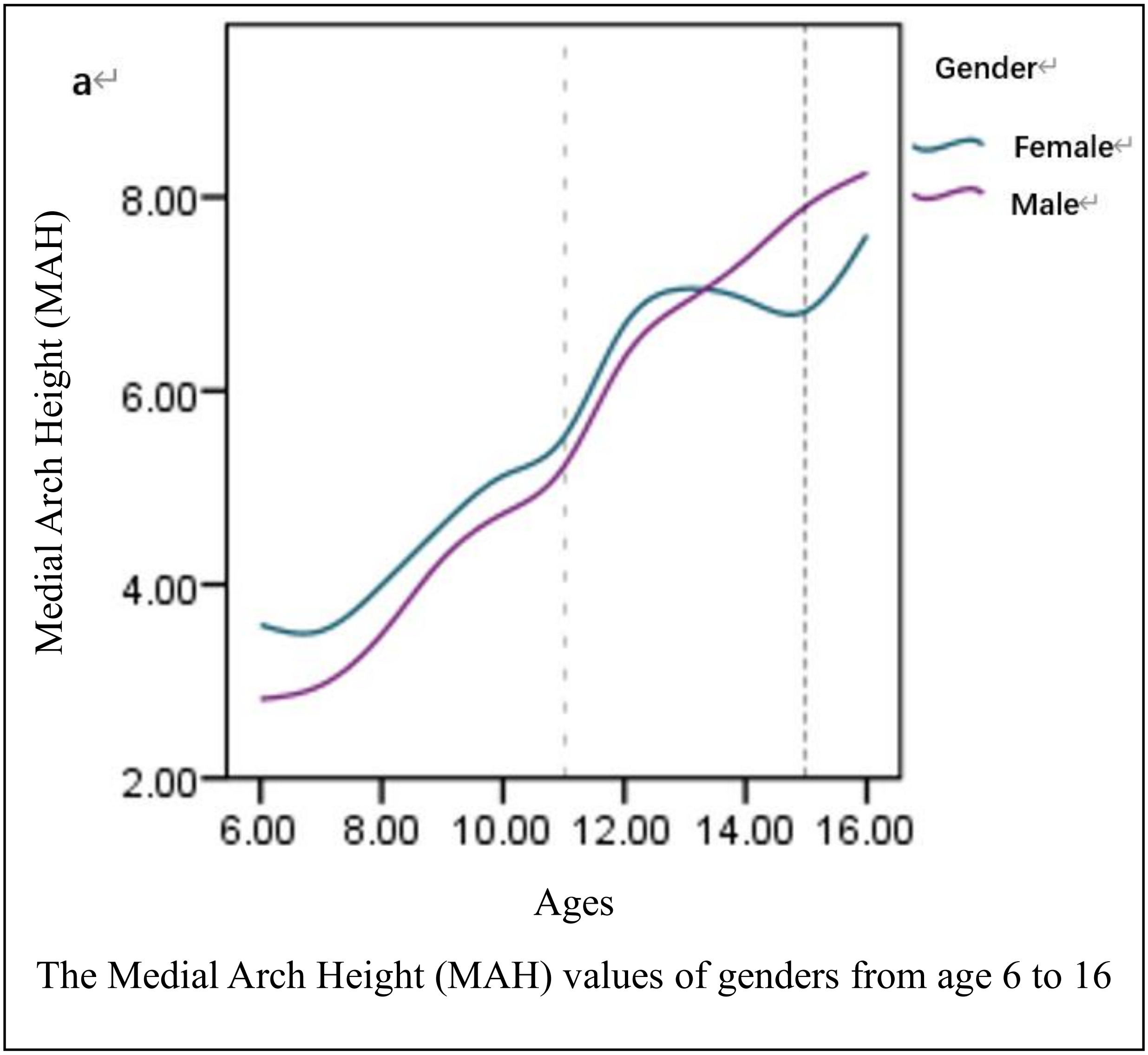


Figure 23a MAH trends between the 2 sexes at different ages

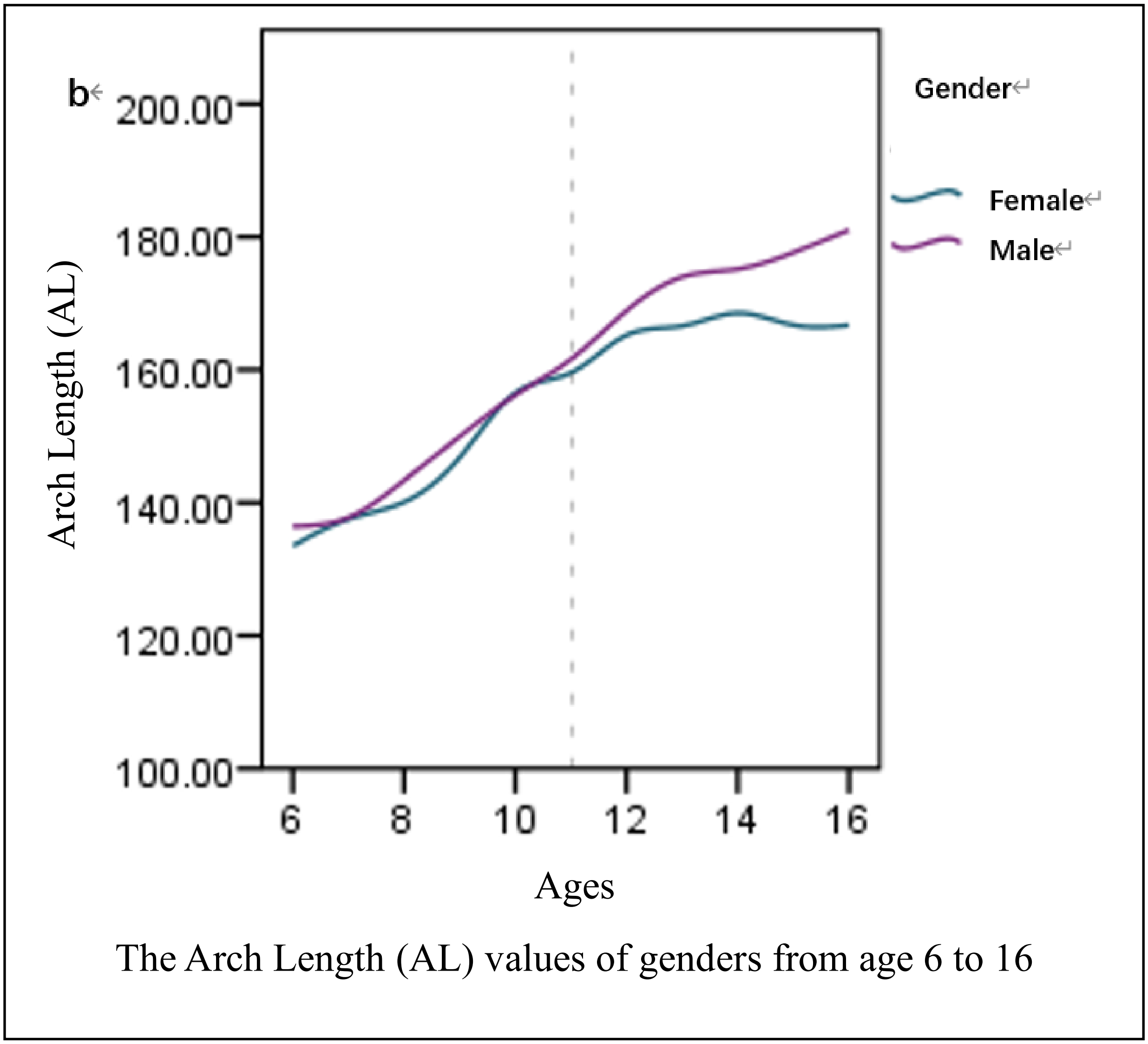
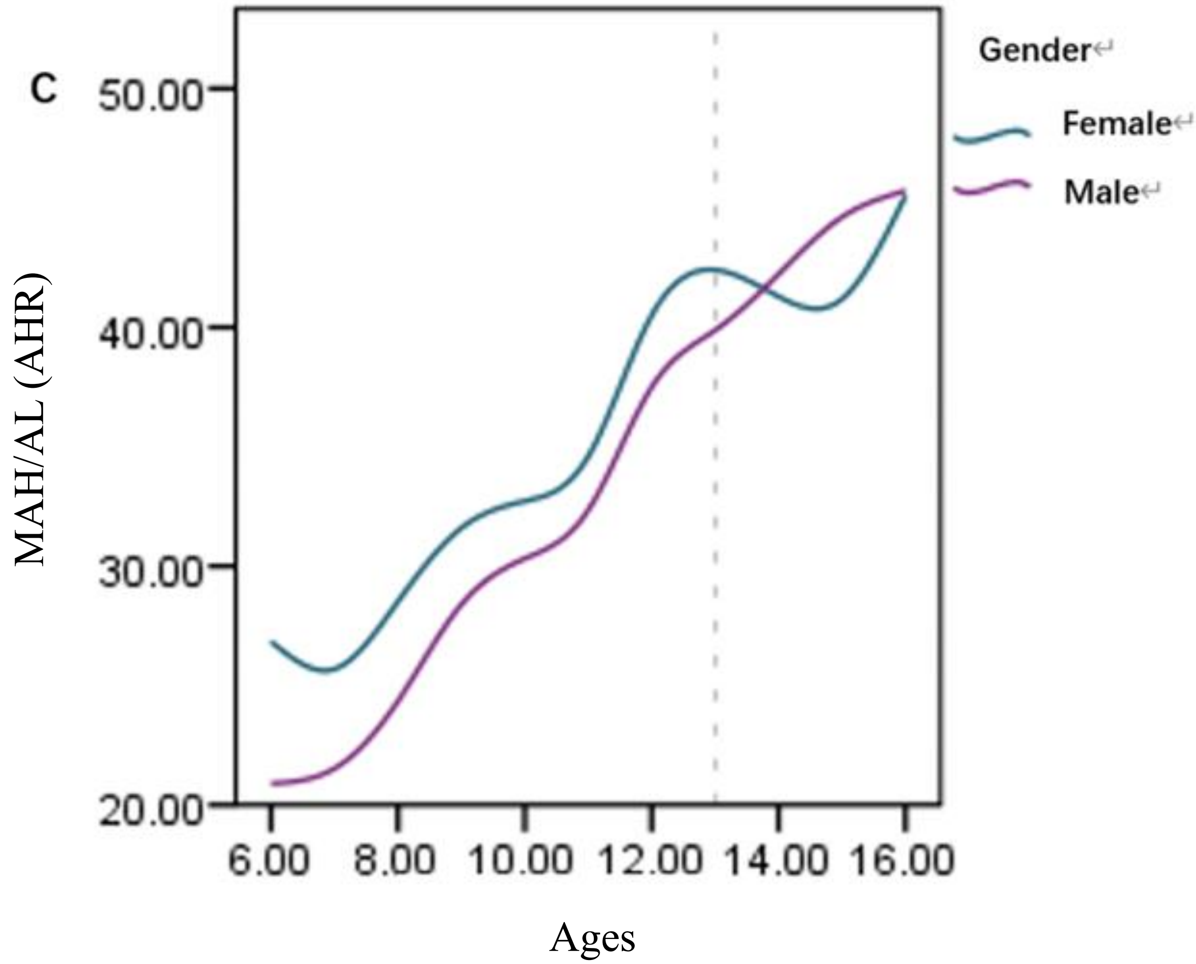


Figure 23b AL trends between the 2 sexes at different ages



The MAH/AL (AHR) values of genders from age 6 to 16

Figure 23c AHR trends between the 2 sexes at different ages

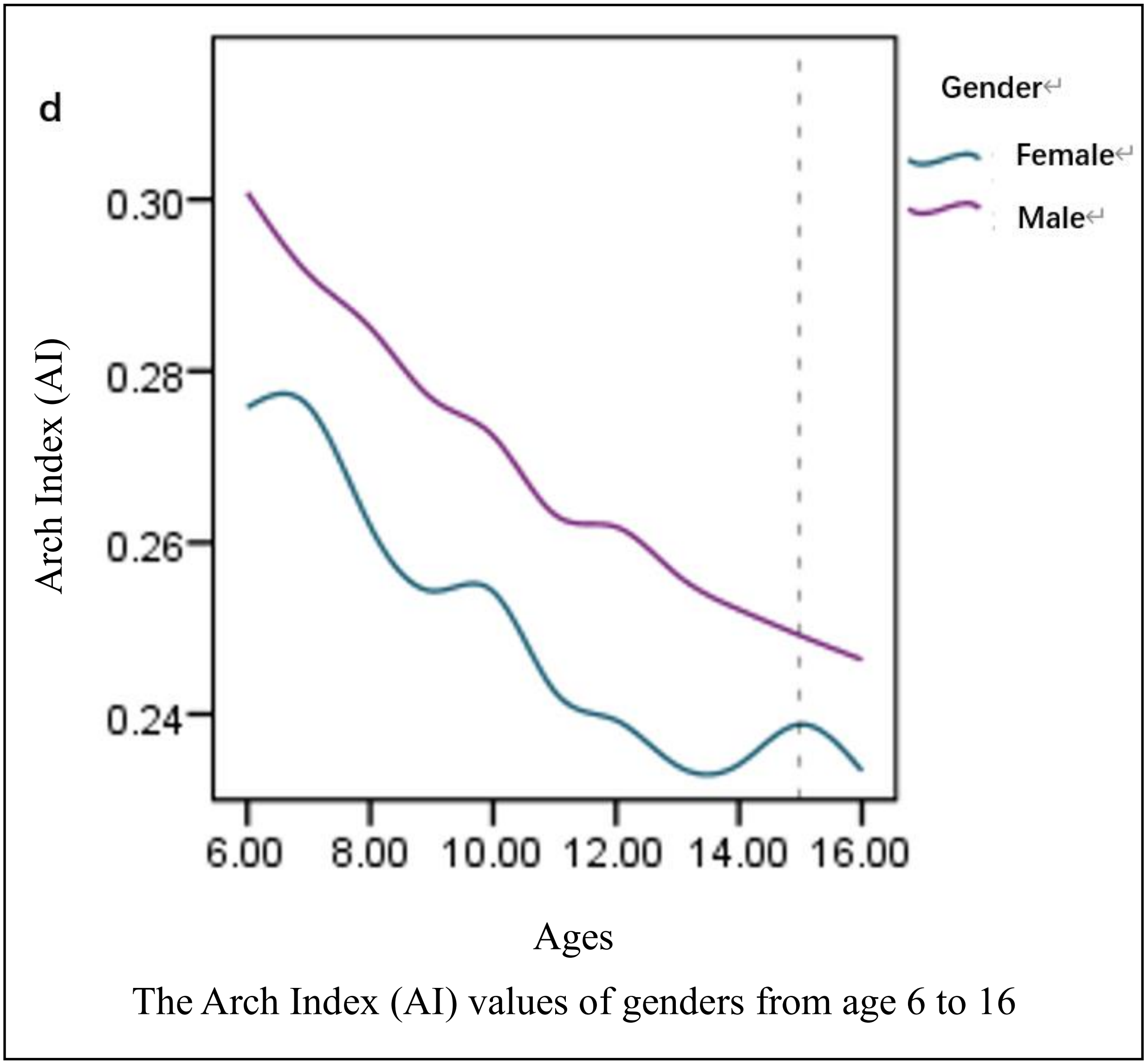


Figure 23d AI trends between the 2 sexes at different ages

Chapter 5 Discussions

5.1. Correlation among parameters

5.1.1. Correlation of Arch Index (AI) and Arch Height Ratio (AHR)

There was a strong and negative correlation between the AI and AHR found. The Spearman's rho correlation coefficient was r = -.740, the relationship was significant (p = 0.00). The strong correlation between the AI and AHR was expected. The two parameters were foot arch structure describing index or ratio. The AI was the area ratio of foot print, of which, a higher percentage or a higher value of AI means that the medial arch structure was lower (Cavanagh & Rodgers, 1987); at the same time, a lower foot arch height value presented was directly understandable. The two parameters were naturally in negative correlation. Therefore, with the strong correlation, a simple linear regression analysis with Spearman's adjustment was carried out to derive an equation for easier flat foot differentiation by AI through AHR. That is, AI was the dependent variable and the AHR was the independent variable.

5.1.2. Regression of Arch Index (AI) and Arch Height Ratio (AHR)

It was shown that a flat foot caused abnormal stresses on the foot and lower extremities. The flatted foot demanded the foot supporting muscles to work more, resulting in a more fatigue situation during exercises. The abnormal stress within the foot structures could lead to further foot deformity during growth. And flat foot might cause various complications and consequences throughout a person's life span (Senadheera, 2016). An easily accessible formula for clinical practitioners to differentiate the arch type was productive and valuable. Therefore, AI and the AHR were chosen to form this formula. As the AI was a well-known arch type describing index, at the same time it showed a relatively strong correlation with the AHR, where AHR was conveniently measurable in daily clinical settings. This index requires only rulers in measurement.

An equation was set up as $\acute{y} = 0.318 – 0.17x$. The r^2 for this equation was .483; that was, 48.3% of the variance in AI was predictable of the level of AHR. This was a moderate strong relationship (Cohen, 1988), which could predict the AI by a single independent variable, the ratio of Medial Arch Height (MAH) and Arch Length (AL). AI was relatively complicated to be obtained in clinics or hospitals. On the other hand, the MAH and AL were far easier to access to. This equation would shorten the assessment of flat foot through AI by two simple measurements. The criteria to obtain a valid result was that the patient being measured must be in the age range of 6 to 16.

5.1.3. Correlation of Arch Index (AI) and Valgus Index (VI)

It was found that the correlation between the AI and VI was in a weak and positive correlation, which Spearman’s rho coefficient $r = -.294$, and statistically significant ($p = 0.00$).

As the AI and VI were widely accepted ratios in describing foot arch, the correlation between these indexes was suggested to be looked at under the same grouping. The correlations of these indexes were relatively weak. This result was reasonable in that, not every flat foot structure having a calcaneal valgus condition. A flat arch patient with relatively standing upright calcaneus was not a rare case. The flat foot was a complex deformity during weight-bearing. It consisted of the Mid-Tarso Joint and Sub-Talar Joint interactions. Therefore, AI and VI were suggested to be used in separate considerations.

5.1.4 Correlation of Five Regions to Arch Index (AI), Valgus Index (VI), and Arch Height Ratio (AHR)

There was only a very weak correlation between the Five Regions and VI, whereas AI and AHR showed no association with the Five Regions. This result was not aligning with the clinical observations by the author. The observation was that more northern kids had higher arches while southern kids' arches were lower in general. The differentiation might be due to the uneven distribution of data populations. Most of the data were from Shanghai and Guangdong, while the sum of the northern and western data was only 20% of the total population.

5.1.5. Correlation of BMI to Arch Index (AI), Valgus Index (VI), and Arch Height Ratio (AHR)

There was a weak correlation between the Five Regions and VI, whereas AI and AHR showed no association with the Five Regions. This result was different from what Sadeghi-Demneh and his team reported in Iran in 2015. They found that a more overweight individual showed flatter feet (Sadeghi-Demneh et al., 2016). At the same time, Ester from Spain, Chang from Taiwan, Senadheera from Sri Lanka, Ezema from Nigeria, and Pourghasem from Iran shared similar results in 2012 (J.-H. Chang et al., 2010; Ezema et al., 2014; Jiménez-Ormeño et al., 2013; Pourghasem, Kamali, Farsi, & Soltanpour, 2016; Senadheera, 2016). The stated authors found a relationship between the overweight and flatter foot, whereas this study only found a weak association between BMI and VI, and no correlation between BMI and AI.

5.1.6. Correlation of Age to Arch Index (AI), Valgus Index (VI), and Arch Height Ratio (AHR)

All three parameters (AI, VI & AHR) had a moderate correlation to Age. It was obvious that the arches grew up higher when age advanced. The structure would get more mature in growth. Park and colleagues found a linear relationship between age and arch height (K.-N. Park et al., 2022). When age advanced, less prevalence of flat foot was reported (Senadheera, 2016). As it would be worth doing further investigation, the prevalence of flat foot with ages would be presented later in this report.

5.1.7. Correlation of Gender to Arch Index (AI), Valgus Index (VI), and Arch Height Ratio (AHR)

The AI and VI showed a weak correlation to Gender, while AHR was barely correlating to Gender. In Nigeria and Taiwan, it was concluded that the prevalence of flat foot in boys was two times as girls (J.-H. Chang et al., 2010; Ezema et al., 2014). On the other hand, Sadeghi-Demneh et al and Senadheera et al found no relationship between Gender and flat foot (Ebrahim Sadeghi-Demneh et al., 2015b; Senadheera, 2016).

5.1.8. Correlation of Pain occurrence to Arch Index (AI), Valgus Index (VI), and Arch Height Ratio (AHR)

All three parameters showed no correlation to the Pain occurrence. The pain occurrence was reported in the questionnaire by the subjects during the data collection process. The results demonstrated that over half of the Chinese kids between the age of 6 to 16 experienced pain in their school life. However, these painful feelings did not have a relationship to flat foot structures. Up to the author's knowledge, there was no similar study determining pain and flat foot association. No comparison could be done in this report.

5.2. Growth trend

Several large-scale studies were focusing on children and adolescent feet (Ebrahim Sadeghi-Demneh et al., 2015b), (Ozlem El et al., 2006), (Kerstin Bosch, Gerß, & Rosenbaum, 2010), (Müller, Carlsohn, Müller, Baur, & Mayer, 2012), (Andrea Naomi Onodera et al., 2008), (J.-P. Chen, M.-J. Chung, & M.-J. Wang, 2009), (Martin Pfeiffer, Rainer Kotz, Thomas Ledl, Gertrude Hauser, & Maria Sluga, 2006), (J. J. Echarri & J. F. Forriol, 2003), (K.-N. Park et al., 2022); however, among those studies, aiming at the growing pattern of the kid's arch shapes were rare. What's more, those findings were retrieved indirectly by footprint measurements only (C. H. Chang et al., 2014; Chen et al., 2011; J. J. Echarri & F. Forriol, 2003; Jimenez-Ormeno, Aguado, Delgado-Abellan, Mecerreyes, & Alegre, 2013; A. K. Leung, J. C. Cheng, & A. F. Mak, 2005; M. Pfeiffer et al., 2006).

From the data distribution, girls had rapid arch growth from age 6 to 11, and became mature at age 12, whereas boys encountered their arch maturity at age 13. This result closed to the findings which were proposed by Waseda et. al. In this Japanese study, 10155 Japanese subjects were recruited from ages 6 to 18. After studying the parameter of MAH/AL (AHR) of the feet, they found that boys had rapid growth between the age of 11 to 13 and kept steady afterward. As for girls, the same parameter showed that the subjects had their foot arch rapidly grew at age 10 to 12 and stopped growing after age 12 (A. Waseda et al., 2014). While Muller et. al. conducted a study about the Arch Index (AI) on a population aged from 1 to 13 and found that their arches kept growing before age 6 and showed relatively small changes between the ages 6 to 13 (Muller et al., 2012). On the contrary, Forriol and Volpon J.B. found that the foot arch growth rate being at peaks at age 6, slowing down after age 6, and stopped growing until age 12 or 13 (Forriol Campos, Maiques, Dankloff, & Gomez Pellico, 1990; Volpon, 1994b). The possible reason leading to this result might be related to the different selection of monitoring parameters. This study and Waseda et. al research chose anthropometric data to describe the arch, that was AHR of the feet. It was believed that these were more descriptive of the three-dimensional structure. While most of the past works applied footprints to calculate AI. The AI data from this survey indicated that this parameter was not sensitive to identifying minor changes in the shape of the arches. (Girl aged 6 of 0.28 vs. age 16 of 0.23; Boy aged 6 of 0.30 vs. age 16 of 0.25). It was proposed that a larger number of subject populations might be able to show that the AI was statistically significant in describing the foot arch shapes. Applying only AI as a primary indicator for describing the arch shapes might not be sensitive enough. The results affirmed that there was a growth discrepancy between boys and girls. From age 6 to 11, girls grew faster than boys, and there seemed to be no arch shape differences between the two sexes after age 11. In past studies, some of the authors reported that there were foot arch shapes dissimilarity between male and female (J. H. Chang et al., 2010; J. P. Chen et al., 2009; A. N. Onodera et al., 2008; Stavlas, Grivas, Michas, Vasiliadis, & Polyzois, 2005). And research had an opposite point of view on the variation of the two sexes' foot arch shapes (E. Sadeghi-Demneh et al., 2015). It was believed that the reason behind the opposite views could be the variations in the age range in different studies.

5.3. Limitation and improvements

5.3.1. Limitations

There were a few limitations in this project. Firstly, the subject recruitment model was a mixed model of randomized individuals and randomized groups. The schools involved were randomized in some cities across China and the subjects were randomly selected within the school. This model was less randomized when compared to a pure randomized model (i.e., no pre-determined group was present, and every kid participated in open recruitment throughout the country).

Secondly, due to the complicated arrangement of the school authorities (including student availabilities, lesson schedules, holidays, etc) in different cities. The distributions of the schools across the whole of China were not even. Most of the schools that collaborated were located in Shanghai and Guangdong. Over half of the subject data came from the two areas. It led to a less convincing correlation analysis about the parameter "Five Regions".

Thirdly, this study was a mass population survey that we did not control the number of students from different age populations. The data collections were dependent on the student populations in every school. The schools did not inform our data collection team how many students were present on the data collection day. The results turned out that the data about ages 6, 15 & 16 were too inadequate comparatively to other ages. It might lead to a less accurate conclusion on the correlation analysis and growth trends.

Fourthly, it was planned that the relationship between Pain occurrence and the activity level of the subjects would be analyzed with another set of data. The correlation between Pain occurrence and other parameters, like gender, BMI, and Five Regions were studied. It would be valuable to understand the Pain occurrence in relationship with the activity level as well. It was because the pain was common presence in active, or outgoing participants. It would be interesting to look into every age together with activity level and Pain occurrence.

5.3.2. Improvements

The data collection could be improved. Firstly, regarding the wide age range, the younger participants had less cooperation during the foot scanning process which might lead to lower accuracy occurrence. To reduce such situations, repeated scanning procedures were performed to diminish the errors once the two sets of data had obvious differences or the kids' behavior could not be controlled. Secondly, the subject number at age 6 and age 16 were relatively small when compared to other ages. More communications with schools should be done before data collection, to achieve a certain level of subject quantity management. Thirdly, a more evenly distributed subject population was suggested. The subject's quantity in Shanghai and Guangdong dominated the whole data set. These might affect some of the statistical analysis results in this report. Finally, it was an investigation of the foot arch shapes in a static position, also described as standing, the foot arches were loaded with their bodyweight. The dynamic data were absent. It was recommended that in future studies, dynamic foot data analysis could be collected as well, which was believed to be able to outline the whole picture better.

Chapter 6 Conclusion

In view of the high prevalence of flat feet in the early stage of human life, a substantial number of studies were on this topic. Some of them focused on the foot length growth patterns, some investigated the differences between the two genders in different age ranges. There were more parameters had been analyzed; BMI, width, circumference, and foot print were examples. However, among those reviewed studies, aiming at the growing pattern of the kid's arch shapes was rare.

Through studying foot arch shapes of 8955 boys and girls at the ages of 6 to 16 with 3D foot data capture system had been conducted. The results showed that Arch Index (AI) had a strong correlation with Arch Length Ratio (AHR), which was the strongest association among all parameters. And, therefore, a regression had been done on these two variables to form an equation for clinical practice to classify different arch types by medial arch length and arch height for the age range of 6 to 16.

It was found that the correlation of the Arch Index (AI) and Valgus Index (VI) was the second strongest among all variables, which was easily understandable because both indexes were flat foot related. The last meaningful associations were paired up as Age and AI, Age and VI, Age and AHR, among these variable pairs possessed moderate strong correlations. While other parameters showed very weak or no correlations in this study.

Finally, both genders' foot arch started a rapid growth at age 6. It was found that girls' arch got mature at age 12 while boys' arch slowed down growth at age 13. Furthermore, throughout the growing period of age from 6 to 11, female grows faster than male. From age 12 onwards, the arch shapes of the two groups did not indicate a significant discrepancy. Male Arch Index showed a higher value than female along all ages in the studied subjects.

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Appendix

Appendix A Questionnaires

上海地区儿童及青少年运动及相关损伤的调查研究

研究发起人：陈世益

复旦大学运动医学中心

中国关心下一代儿童基金会

亲爱的同学们，大家好!

本研究旨在调查上海地区儿童及青少年日常运动情况及运动相关损伤的发生情况。问卷共分为三个部分。第一部分学生基本信息；第二部分为日常运动水平调查；第三部分为日常运动损伤情况调查。

请同学们仔细填写问卷，平均填写时间为 3-5 分钟。

学生基本信息

- 班级：(　　　　　　　　　)
- 姓名：(　　　　　　　　　)
- 性别：(　　　　　　　　　)
- 年龄：(　　　　　　　　　)
- 星座：(　　　　　　　　　)
- 血型：(　　　　　　　　　)
- 身高：(　　　　　　　　　)
- 体重：(　　　　　　　　　)
- 爸爸年龄：(　　　　　　　　　)
- 妈妈年龄：(　　　　　　　　　)

参加运动情况

1. 请问您参加最多运动（游戏）是？ ______________________________ （若无可不填）

2. 过去三年中，请问您每周大约能参加几次运动（游戏）？

☐ A：从不参加　　☐ B：1-2 次　　☐ C：3-5 次　　☐ D：＞5 次

3. 过去三年中，请问您参加运动（游戏）的时间每次大约为多少？

☐ A：＜60 分钟　　☐ B：60-120 分钟　　☐ C：121-180 分钟　　☐ D：＞180 分钟

4. 您在日常运动（游戏）中，是否有人给予指导？

☐ A：专业老师指导　　☐ B：非专业人员指导　　☐ C：自由玩耍

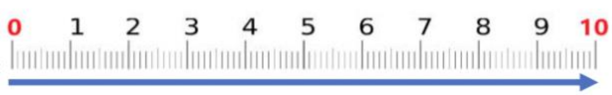
5. 您的爸爸参加运动么？（如有特殊情况，可不填）

☐ A：爸爸经常运动　　☐ B：爸爸偶尔运动　　☐ C：爸爸很少运动　　☐ D：爸爸从不运动

6. 您的妈妈参加运动么？（如有特殊情况，可不填）

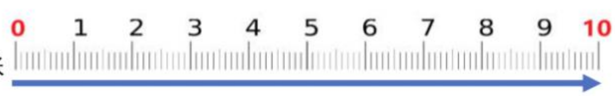
☐ A：妈妈经常运动　　☐ B：妈妈偶尔运动　　☐ C：妈妈很少运动　　☐ D：妈妈从不运动

6. 运动（游戏）能给你带来快乐么？

毫不快乐


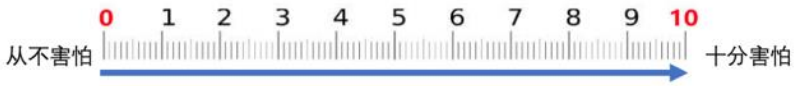
十分快乐

7. 运动（游戏）中你会感到紧张么？

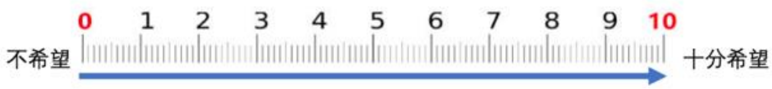
从不紧张


十分紧张

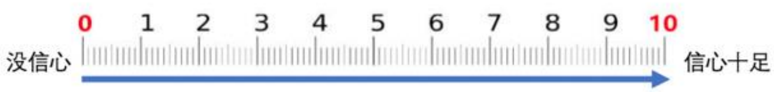
8. 你害怕在运动（游戏）中进行身体对抗么？



9：您希望将来成为一名职业运动员么？



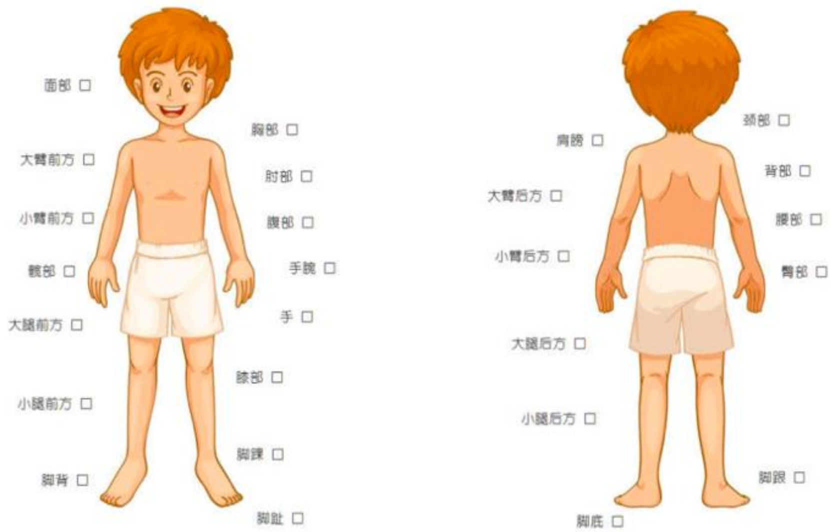
10：您有信心将来成为一名职业运动员么？



运动损伤情况

如您在过去三年中出现因运动导致的伤痛，请在下图对应身体部位的“☐”中打“√”，并回答以下问题。

如您从未出现因运动导致的伤痛，则不需填写。



1.伤痛出现在哪侧？

☐ A: 左侧　　☐ B：右侧　　☐ C：双侧

2. 伤痛出现的次数？

☐ A：1 次　　☐ B：2-4 次　　☐ C：4-6 次

3. 伤痛持续的时间？

☐ A：＜3 天　　☐ B：3-7 天　　☐ C：1-3 周　　☐ D：＞3 周

4. 是否接受治疗？

☐ A：接受治疗　　☐ B：未接受治疗

如果过去三年中您的脚部曾发生不适（酸胀、肿胀、疼痛），请在下方 4 张图中的相应区域准确标记对应的地方，打“√”即可。

脚内侧区域

脚外侧区域

脚底

脚背

http://www.zaratepodiatry.com/foot-pain-interactive-tool/#fourth

本问卷到此结束，感谢您的耐心回答！