Foot Arch Posture Development in Children and Adolescents aged 6 to 19 Years: A Cross-sectional Descriptive Study

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Research

Keywords: arch height index (AHI), foot arch posture, childhood , adolescence

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Abstract

Background: The arch height index (AHI) is a commonly used method for measuring foot arch posture. However, there are little studies have investigated the natural growth and normative values of the foot arch using the AHI. The objective of this study was to establish normative and cut-off values for foot arch posture and to identify factors influencing foot arch posture across childhood and adolescence.

Methods: In this cross-sectional study, a sample of 3532 healthy children and adolescents (1804 boys, 1728 girls; aged 6 to 19 years) was recruited for the navicular height (NH) and AHI measurements and anthropometry assessment (weight, height, BMI and foot length). Data were explored descriptively and graphically, comparisons between groups used t-tests or ANOVA model as appropriate and a multiple regressions was conducted. The 95% and 68% prediction intervals were used as cut-off values.

Results : approximately 69% had a normal AHI range, 12% low arched foot, 3% severely low arched, 14% high arched and 1.8% severely high arched foot. The mean (SD) AHI was 15.16 (2.61). Very little gender bias was found for AHI values, being higher in males 15.32 (2.54) than in females 15.0 (2.68) ($p = .019$). Regression showed approximately 3%, 0.3% and 2% of the AHI change was explained by age, BMI and foot length, respectively. The mean NH significantly increased from the age of 6 (2.62 cm) to 19 (4.20 cm).

Conclusions: This study confirms that the ‘flexible flatfoot’ or low arched foot decreases with age. Simultaneously, increase of high arched foot type and shift in foot posture towards more normal foot type are also confirmed. BMI does not seem to be an important determinant of children foot arch posture.

Keywords: Foot posture, Navicular height, Arch height index, Normative values, Medial longitudinal arch, Foot arch development, Children, Adolescents

Background

The ‘flatfoot’ has referred to a low or absent medial longitudinal arch (MLA), with the heel in excessive valgus position [1]. The present consensus is that foot arches are not present at birth but evolve with the progression of weight bearing [2]. Accordingly, flatfoot becomes apparent from birth and is often seen in children before 8 years of age [3], due to ligament laxity, young musculature, increased adipose tissue and immature neuromuscular control [4]. Gould et al. [5] described flatfeet in all children examined between 11 and 14 months of age. With variation, as children approach gait parameters similar to those of adults, the majority of children develop an adult-like arch and flatfoot posture reduces with age [6].

Children’s foot posture has been evaluated using different methods including anthropometric (clinical) measures [7–9] radiographic evaluation [10], footprints parameters [11] and foot posture index [6, 12]. Anthropometric (clinical) approaches to characterise the foot posture involve direct measurement of surface landmarks or bony eminences representing the location and position of different structures within the foot, including the MLA. Findings agree that direct measurement of the highest point of the MLA in the sagittal plane is one of the primary criteria for the categorising of foot type (flat/normal/ high arch) and the simplest methods of providing the clinician with quantifiable information regarding foot arch posture [13]. The navicular height (NH) generally represents the highest point of the MLA and enables the classification of the foot arch structure [7, 9, 13, 14]. Sell et al. [15] reported an intraclass correlation coefficient (ICC) ranging from 0.73 to 0.96 for the interrater and intrarater reliability for NH. The agreement between clinical and radiographic measurements was reported to yield ICCs of 0.87 and 0.91 for NH and 0.91 and 0.92 for arch height index (AHI) in 10 and 90% of weight bearing, respectively [16].

The majority of previous studies on normative reference data for foot posture have been conducted in the developed countries; but it is possible that because of cultural, geographical and environmental differences, heredity, nutrition and footgear their impacts are not the same in other countries. Thus, studies investigating normative values for symmetry and cut-off values to identify asymmetrical foot postures across feet in the developing countries are increasingly needed.

The aim of this study was to assess foot arch development of children and adolescents aged from 6 to 19 years, using the NH and AHI measurements noting any association with age or anthropometric factors (BMI and foot length) and to establish normative values for foot arch posture across childhood and adolescence.

Methods

Participants

This cross-sectional study consisted of 3532 students (8104 boys, 1728 girls) aged 6 to 19 years. Data were acquired from 6 elementary schools, 6 secondary schools and 4 high schools where randomly selected in Tabriz (Iran), from January to November 2019. The mean age was 12.43 (SD 3.74), while the mean BMI was 19.60 (SD 3.60) kg/m^2. The demographic and anthropometric characteristics of the study population are presented in Table 1 and 2.

The criteria for inclusion were; students of both genders, and aged 6 to 19 years. Students with musculoskeletal disorders, congenital abnormalities (e.g., unequal lower limbs, scoliosis), and any pain, surgery and traumatic injury in the lower extremity were excluded from the study. 35 of the participants were excluded from the study (due to pain, surgery and traumatic injury in the lower limb). The purpose of the study was explained for each participant and their parents. Informed consent was obtained from participants and their parents. The study was in accordance with the Declaration of Helsinki and was approved by the ethics committee of the university.

Anthropometric measurements

Weight was measured via a calibrated digital scale to the nearest 0.1 kg with lightweight clothes and no shoes. Standing height was measured using a calibrated altimeter. The body mass index (BMI) was calculated for participants by dividing the weight by the square of the height. A ruler (in millimetre, ABS Plastic) was used to measure foot length (FL) from the heel's rear surface to the tip of the first toe.

Arch height measurement

Foot arch height was assessed by measuring vertical height of the navicular bone with the subjects barefoot, in a relaxed double limbs standing (with their body-weight evenly distributed on the two feet) and upright position on a platform at 50 cm above the floor to facilitate visual and manual inspection of the navicular by the investigators. The navicular tuberosity was palpated and the most prominent point marked on the skin. Using a ruler the height of this mark from the supporting surface for both feet was then measured and reported in millimetres. In order to normalise the arch height irrespective of the foot length change, which is clearly observed with age in children and adolescents, the arch height index (AHI = navicular height divided by foot length [AHI (%) = NH/FL x100]) was also calculated. Reference ranges for the AHI were defined using the cut-off points employed previously for similar studies [9,12] including (a) Normal: values lying in the range, mean +/- 1 standard deviation (SD), (b) Potentially abnormal: values 1 to 2 SDs from the mean, (c) Pathological: values lying outside 2 SDs from the mean.

Statistical Analyses

By pooling data from right and left feet, the assumption of independence is violated [17]. Therefore, based on the strong correlation between NH measures on right and left feet in participants ($r = 0.828$, $p < 0.001$), for further subsequent analysis only the left side (chosen at random) was used for statistical analyses.

Descriptive data were presented as mean, standard deviation (SD) and 95% confidence interval (95% CI) for continuous data and as number and percentage for dichotomous data. Testing for normality using a Kolmogorov-Smirnov test, found normal distribution of all data. Differences in mean NH and AHI between males and females were analysed using t-test. ANOVA with Tukey's post hoc test was used to compare the mean NH and AHI between age groups (6 to 19 years). Multivariate linear regression analysis was used to test the associated between independent variables (age, BMI, foot length) with NH and AHI. The AHI cut-off points, defining foot type category were used, i.e., a) severely low arched <-2 SDs from the mean, b) low arched -2 to -1 SDs from the mean, c) normal ±1 SD from the mean, d) high arched +1 to +2 SDs from the mean, e) severely high arched >+2 SDs from the mean [9]. Statistical Analysis were performed using IBM SPSS Statistics (version 23, SPSS Inc, Chicago, USA). The p value less than 0.05 was considered statistically significant.

Results

The mean (SD) NH was 3.64 (0.77) cm for males (range, from 1.5 to 6.4 cm), and 3.40 (0.62) cm for females (range, from 1.4 to 5.6 cm). The mean (SD) AHI was 15.32 (2.54) for males (range, from 6.42 to

24.12), and 15.0 (2.68) for females (range, from 6.82 to 23.25) (Fig 1, NH and AHI left feet).

A significant difference (t = 5.46, p = 0.000, very small effect size) was found in the NH measures between genders, being higher in males with the mean of 3.64 cm (0.7) than females with the mean of 3.40 cm (0.6). Similarly, we found very little gender bias for AHI values (t = 2.34, p = 0.019), with the mean for males 15.32 (2.5), and for females, mean 15.0 (2.6) (figure 2). There was strong correlation between NH and age (r = 0.522, p = 0.000) (Fig 2). The correlation between AHI and age was weak, if significant (r = 0.126, p = 0.000).

Analysis of variance test showed a statistically significant differences between the age groups in the NH measures (F = 53.87, $p < 0.001$, large effect size) (Table 2). Difference between the age groups in AHI values, while also statistically significant, was very small (F = 4.43, $p < 0.001$, very small effect size). The mean NH in males significantly increased from the age of 7 to 14. Although there was no significant difference for males over 15 years old. In females, the NH significantly increased from the age of 6 to 13. Although no significant difference appeared for females over 14 years old. The growth rate of the NH was lower in females compared with that in males after 12 years old (Table 2, Fig 2). These differences were confirmed as significant by Tukey's post hoc test ($p < 0.01$).

In the study population of 3532 children and adolescents, flat foot or low arched foot was found in 11.9% (n = 421), normal in 69.4% (n = 2452), yielded flatfoot or severely low arched in 2.9% (n = 103), high arched foot in 13.9% (n = 492) and severely high arched in 1.8% (n = 64). Table 4 used designated AHI categories to define and explore the range of foot arch height across childhood and adolescence.

Exploring the association between foot arch categories and age groups across AHI ranges showed that the prevalence of flat or low arched foot decreases significantly with age, which supports the clinical observation of less flatfoot in older children. In the group of 6-year-old children, 27.6% showed a low arched foot, whereas in the group of 19-year-old adolescents only 5.9% had a low arched foot ($P < 0.001$). The severely low arched group also varied with age, from 4.7% to 2.9% from 6 to 19 years. A similar but inverse trend was seen in the normal, high arched and severely high arched foot categories, which increased with age, by 70.2%, 18.9% and 2.0%, respectively (Table 4).

The multivariate linear regression between NH and age or anthropometric characteristics showed that age (b = 0.059), BMI (b = 0.012) and foot length (b = 0.095) are able to explain the 31% (r^2 = 0.314, $p <$ 0.001) of the whole NH value. The analysis also showed that age, BMI and foot length were associated with AHI. Around 3% (r^2 = 0.034, $p < 0.001$) of the whole AHI value could be explained by age (b = 0.26), BMI (b = 0.051) and foot length (b = -0.255) (Table 5).

Discussion

Despite the many investigations on development of the foot arch, little is known about the direct measurement of foot arch height and cut-off values in children and adolescents. This study is a large-scale investigation to assess natural history of children and adolescents foot arch height using the direct measurement of the MLA, to establish normative and cut-off values for the AHI, and to analyze associations between age or anthropometric characteristics and foot arch across childhood and adolescence. This investigation of foot arch posture includes healthy children and adolescents aged from 6 to 19 years.

This study confirms that the mean NH and AHI increases with age in a linear pattern, from 2.62 cm and 13.9 at age 6 years to 4.19 cm and 16.4 at age 19 years, respectively. Importantly, the NH range of variation was broad: 1.4 to 3.6 cm at age 6 years, and NH 2.7 to 6.4 cm at age 19 years. Flatfoot or low arched foot was generally found to decrease with age. In this study, the prevalence of flat foot was 11.9%; the prevalence decreased from 27.6% in 6-year-old children to 5.9% in 19-year-old adolescents. This study also found very little gender bias for NH measures and AHI values. These statistical differences demonstrated that males have a mean NH and AHI, 3.64 cm and 15.32 versus 3.40 cm and 15.0 in females, respectively.

In the current study, normative and cut-off values for normal and abnormal difference in AHI among different age (years) groups based on the 68% and 95% prediction intervals were presented. The mean foot arch in the children and adolescents, as found in this study was AHI 15.16 (2.61). Clinically this implies that around 68% of study population have AHI measure between ± 1 SD from the mean, range 12.5 to 17.7 (AHI normal category) (Table 3). Further, around 95% have AHI value between ± 2 SD from the mean, range 9.9 to 20.3 (AHI low arched, normal and high arched categories) (Table 3). Clinical alert is indicated for foot arch > ± 2 SD, representing 5% of expected abnormality (Table 3).

To our knowledge, no studies have reported cut-off values for AHI (NH/FL) in children and adolescents. However, several studies [7, 16, 18] have reported mean values for AHI in different age groups, but our findings differ slightly from the results in these studies. Waseda et al. [7] in a large-scale investigation of the foot arch have reported a mean AHI of 14.9 in 6 to 18 years old children and adolescents. Our higher AHI (15.1) may be related to the age range of students in this study (6 to 19 years old) in comparison with the study by Waseda et al. [7]. In the study by Williams and McClay [16] they reported mean AHI of 16.3 for a sample of younger and older adults (mean age 27). That study [16] was a reliability study investigating the reliability and validity of several measurements of the MLA in adults 19 to 43 years old and different weight bearing, and was therefore not designed to investigate normative values. Morita et al. [18] reported a mean AHI of 14.6 and 14.2 in 9- and 11-year-old children, respectively. The mean values of 14.7 and 14.6 reported in the current study in children aged 9 and 11 year, respectively; were close to the proposed values reported by Morita et al. [18].

More importantly, the findings in our study showed that the mean NH in males gradually increased to the age of 11 and then accelerated from the age of 12 to 14 years and tended to increase after the age of 14. In females the mean NH gradually increased to the age of 10 and then accelerated from the age of 11 to 12 years and reached a plateau at 16 years of age. The NH tended to increase after the age of 14 in both genders but there was small degree of changes and not significant. This outcome may be associated with the process of development of the foot arch, which is in agreement with previous studies by Waseda et al. [7] and Rai et al. [19] that have reported an increase in the longitudinal arch with age, using NH measurement method.

This study found minimal differences between male and female foot arch posture in the NH and AHI values. This is again corresponds well with other recent studies that have reported little gender bias, despite using other measurement techniques such as footprints, radiological and anthropometrical measures or observational techniques [12, 20–22].

In the current study, we found that age and foot length are indicative associated factor with foot arch posture. This finding is in accordance with previous studies [9, 21, 24, 25], which show that age and foot length had a significant association with foot arch posture. In agreement with earlier studies [6, 12, 24], we found that BMI does not seem to be an important predictor of children foot arch posture. While other studies found BMI to be related to foot arch posture in children [26, 27]. The results in the literature regarding the association between BMI and foot arch posture in children are still inconclusive.

Some helpful insights can be derived from this study. A low arch AHI category, and even severely low arch, can be expected in children aged less than 8 years. Hence, in the first decade of life, the presentation of a child with low arched foot (flexible flatfoot), which is painless, can usually be confirmed as normal for age [23]. The severely low arched and severely high arched foot postures, must be considered as 'abnormal', with approximately 2.9% and 1.8%, respectively seen in this sample of children and adolescents (Table 4). Thus, in the physical examination of foot arch posture, clinicians must more closely consider the severely low and high arched foot (as a clinical/neurological alert) than the asymptomatic low arched foot [6].

The findings of this study have important implications for clinicians, parents and future research. Such normative reference data help appreciation of the range of 'normal range' for foot posture [12]. Further, the children flatfoot that is becoming flatter as a child becomes older should alert clinicians, and direct differential diagnoses, for factors such as joint hypermobility, connective tissue disorders, altered neurological tone or muscular conditions [6]. The data also provides mean and standard deviation values to act as comparators for future studies in a range of potentially pathological groups.

The present study has some limitations. First, the sample of the study population was students between 6 and 19 years old and results could not be generalized to other age groups. Second, it may be difficult to palpate the tuberosity because of the navicular bone's round shape and the undesirable influence of the local soft tissue [7]. Finally our study is cross-sectional and can only provide some insights, a prospective longitudinal study is needed to clearly show foot arch change over time

Conclusion

This study of children and adolescents foot arch posture, confirms that the flexible flatfoot or low arched foot is the common foot posture in children (aged less than 8 years). The low arched and severely low arched foot types were found to decrease with age. Simultaneously, increase of both high arched and severely high arched foot types was also confirmed. Higher BMI was not associated with foot arch posture. The normative reference data and cut-off values produced from the findings of this study could be helpful to develop clinical strategies for diagnosis and treatment of flatfoot in the children and adolescents.

Abbreviations

MLA: medial longitudinal arch; NH: Navicular height; AHI: arch height index; BMI: body mass index; FL: foot length; SD: standard deviation; CI: confidence interval; ICC: intraclass correlation coefficient

Declarations

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Authors' contributions

YM has made substantial contributions to conception, design, analysis, and interpretation of data, and was a major contributor in writing and preparation of the manuscript. RA carried out the acquisition of data and has been involved in drafting the manuscript. All authors read and approved the final manuscript.

Ethics approval and consent to participate

The study was in accordance with the Declaration of Helsinki and was approved by the Ethics Committees of Payame Noor University of Tehran (Iran).

Consent for publication

Not applicable

Competing interests

The authors declare that they have no competing interests.

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Tables

Due to technical limitations, all tables are only available as a download in the Supplemental Files section.

Figures

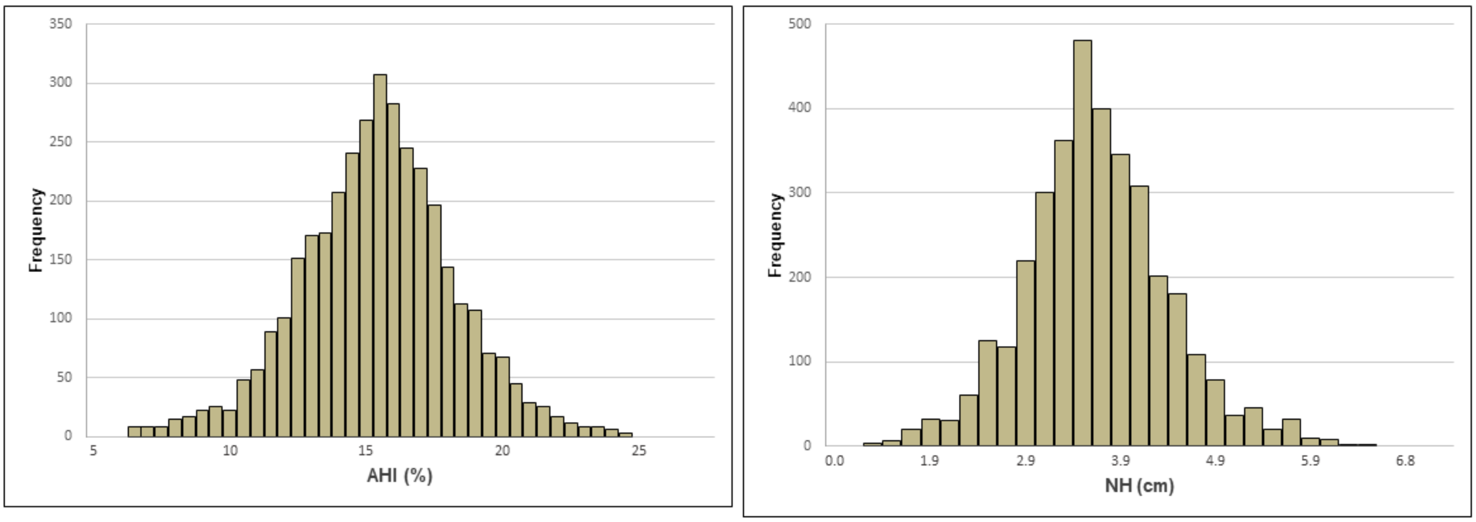
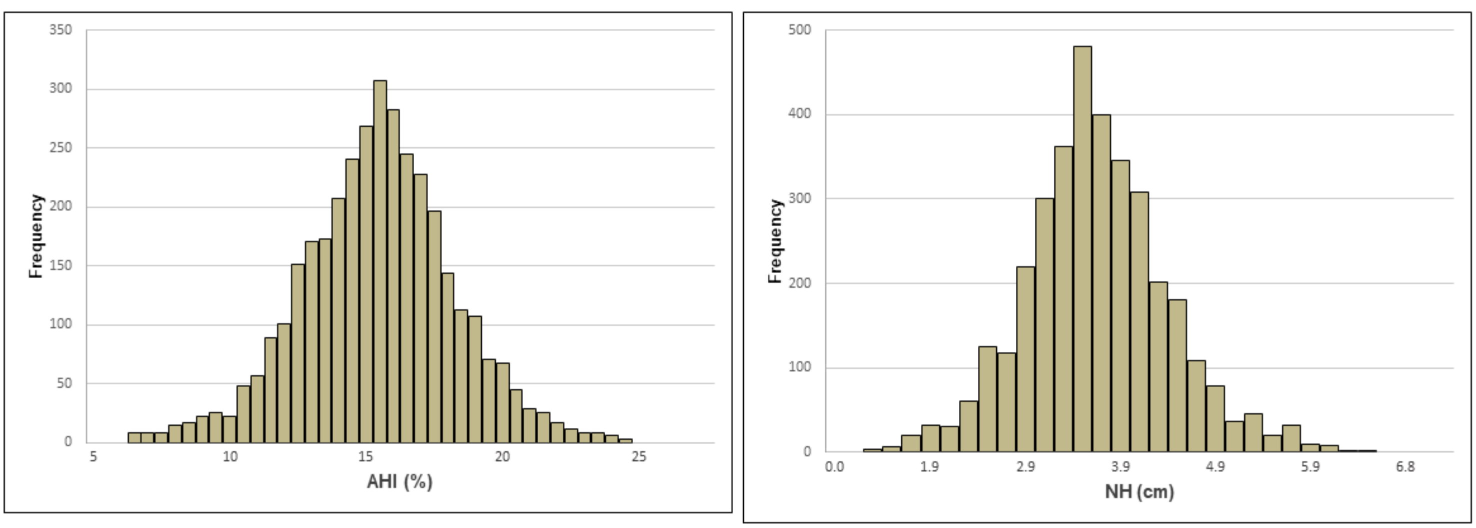


Figure 1

Frequency plot of the AHI values and NH measures (N =3532) AHI and NH presented a normal distribution



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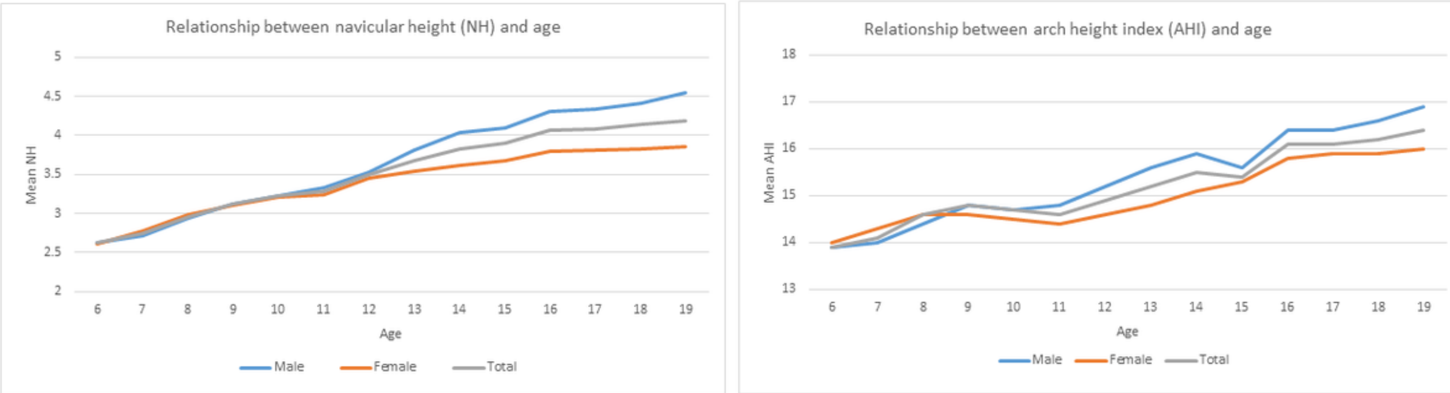

Figure 2

Graph of linear changes in NH and AHI for gender and age

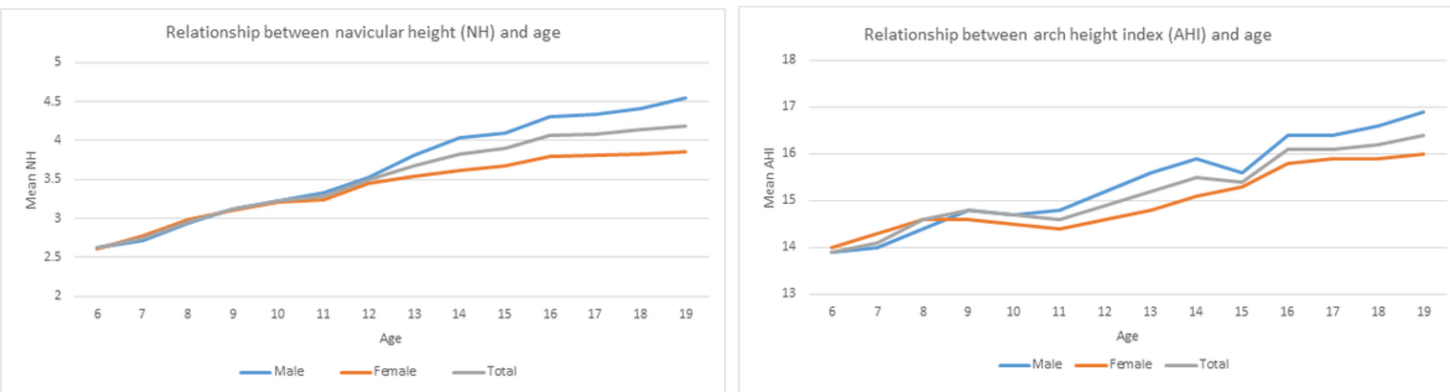

Figure 2

Graph of linear changes in NH and AHI for gender and age

Supplementary Files

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