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REFERENCE BASELINE VALUES FOR CALCANEAL QUANTITATIVE ULTRASOUND PARAMETERS IN NIGERIAN CHILDREN: RELATIONSHIP WITH BODY MASS INDEX AND SERUM CALCIUM

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ABSTRACT

Background: Bone health is crucial in childhood development, yet access to Dual-energy X-ray absorptiometry (DEXA) for assessing bone density is limited in Nigeria. Calcaneal Quantitative Ultrasound (QUS) provides a more accessible, non-invasive, and radiation-free alternative for evaluating bone density in resource-limited settings. Despite its potential, there is a lack of established reference values for QUS parameters in Nigerian children.

Objective: This study aimed to establish reference baseline values for calcaneal Quantitative Ultrasound Index (QUI) and Estimated Bone Mineral Density (eBMD) in healthy Nigerian children. It also investigated the relationship between BMI, serum calcium levels, and bone density.

Methods: The Sahara bone sonometer was used to measure the QUS parameters of 494 boys and 522 girls in this cross-sectional study. The participants' BMI and serum calcium levels were also measured. Pearson correlation coefficients and a multiple regression model were employed for the test of association and relationship.

Results: Baseline measurements of QUI and eBMD were available in boys with a mean (SD) age of 11.38 (2.32) years, and girls, with a mean (SD) age of 11.47 (2.92) years. The participants' mean QUI and eBMD (SD) were 94.91 (13.37) and 0.52 (0.08) g/cm², respectively, for boys and 92.46 (13.47) and 0.51 (0.09) g/cm² for girls. In both genders, age was a predictor of both QUI and eBMD ($p < 0.05$) while BMI was a predictor of both QUI and eBMD in only the girls ($p < 0.05$). Serum calcium had no relationship with the two QUS parameters ($p > 0.05$).

Conclusion: The study is the first to fill a critical gap in pediatric bone health data by establishing baseline QUI and eBMD values in Nigerian children.

Keywords: Quantitative ultrasound index; calcaneus; children; estimated bone mineral density; reference data; serum calcium

Introduction

The paucity of data on Bone mineral density (BMD) in developing countries has been an existing gap that conceals a clear picture of the present prevalence of osteoporosis in such countries. In Nigeria for instance, osteoporosis is sparingly studied, mostly due to the limited availability of diagnostic resources [1-4]. Measurement of bone mineral density (BMD) in children has become of immense importance as it assists in identifying the children who could be exposed to an increased risk of osteoporosis in adulthood [5].

Dual-energy x-ray absorptiometry (DEXA) equipment, the goal standard for measuring the BMD of individuals, is scantily distributed among a population of over two hundred million [2] in Nigeria, due to the high cost of its acquisition. Secondly, BMD as computed by DEXA in children, equals the ratio of bone mineral content to bone surface area ratio and is associated with great biological disparity in measurements, majorly due to changes in bone geometry because of age-related factors [5]. In addition to that, its use is discouraged in large populations of children because it involves high exposure to ionizing radiation.

However, relatively non-invasive techniques like Calcaneal Quantitative ultrasound (QUS) techniques, among their other advantages of being portable, radiation-free, more child-friendly, more adaptable to large-scale surveys, and able to contribute to the prediction of the risk of future osteoporotic fractures independent of the BMD measured by DEXA, seems to be a lot cheaper than DEXA [3, 6, 7, 8, 9]. Calcaneal QUS can offer a practical way of assessing bone health status using four parameters, two of which are broadband ultrasound attenuation (BUA) and speed of sound (SOS). The rest two are Quantitative Ultrasound Index (QUI), also known as stiffness index (SI), and Estimated Bone Mineral Density (eBMD), which are the composite indexes of the first two parameters, known to offer better precision [5].

Several studies have since established that childhood and adolescence are very crucial periods for bone development, mineralization, and the attainment of a peak bone mass (PBM) [10,11]. Recently, more studies continued to reveal PBM as an important indicator of a conceivable risk of fragility fractures later in life [12]. This implies that a higher PBM may suggest a lower risk of fragility fractures late in adulthood and the prevention of osteoporosis commences by maximizing the bone mineral density an individual gains in his/her growing years [13-15]. It, therefore, becomes imperative to assess the bone health of children to address any bone health challenges earlier in life, improve bone strength, as well as prevent osteoporosis and other bone health challenges later in life.

To commence addressing the epidemiological data on BMD in the Nigerian children population, it is critical to first establish population-specific normative data. Age- and sex-specific bone density reference values can aid in assessing skeletal development in childhood and comparing the bone health status of a child with that of a healthy population having the same age, sex, and ethnicity. Although an attempt has been made to establish QUS reference baseline values among Nigerian children, the parameters yet reported in the literature were only the SOS and BUA [16]. However, studies have shown that QUI and eBMD can be used to strengthen precision [17], highly correlate with DEXA measures [18-20], and are accepted to be more robust in measuring bone strength in both children and adults [21]. Several factors have been named as having influences on bone mineral density, which include but are not limited to body mass index (BMI), physical activity, body composition, dietary intake, Serum Calcium, vitamin D level, genetic predisposition, etc. [14, 12, 22], however, their influence on children and adolescents remains controversial. Whereas some studies noted an association between some of these factors and BMD [23, 10, 24, 25], others have not validated this claim [26, 27], thereby making it crucial for its re-investigation. In Nigeria, and much of sub-Saharan Africa, there is limited research on the relationship between body mass index (BMI), serum calcium levels, and BMD in the Nigerian children population. While BMI has been found to influence bone density due to mechanical loading [28], the role of serum calcium in pediatric bone health remains poorly understood, especially in African populations. This study, therefore aimed to establish calcaneal QUS reference baseline values for QUI and eBMD in healthy Nigerian children aged 6-14 years using a QUS sonometer, while also investigating their relationship with age, gender, BMI, and serum calcium. By providing baseline data specific to the Nigerian pediatric population, this study seeks to address a critical knowledge gap and contribute to the growing body of evidence on pediatric bone health in low-resource settings. Additionally, understanding the impact of BMI and serum calcium on the BMD of children could offer valuable insights for designing targeted strategies aimed at enhancing bone health outcomes in Nigerian children..

METHODS:

Participants

This study, which was prospective, cross-sectional, and community-based in design, involved 494 boys and 522 girls between 6 and 14 years who were randomly enlisted from six elementary and junior secondary schools in the three geopolitical zones of Enugu State, Nigeria. The Enugu State Ministry of Health Ethical Committee reviewed and approved this study (MH/MSD/EC/0222).

Participants were recruited following a rigorous screening process to ensure adherence to the inclusion and exclusion criteria. While we did not systematically record the exact number of excluded participants, all individuals who met any of the exclusion criteria—such as having a disease known to affect bone metabolism, prior medication use affecting bone metabolism, a history of fractures, or lack of parental consent—were not included in the final sample. The final sample size of 1,016 children represents those who fully met the study requirements following this screening process. Other detailed descriptions of the participants have been stated elsewhere[16].

Procedures

Assessment of participants' demographic and anthropometric variables

The participants' demographic information such as age and sex were collected via a questionnaire filled by their parents and confirmed from the class register. The participants' height and weight were measured using standard instruments previously described[16]. Body Mass Index (BMI) was calculated from the height and weight measurements using the formula: Weight/Height² (Kg/m²).

Assessment of the Bone mineral density parameters (QUI and eBMD)

The QUS measurements on the right heel were performed using a Sahara 06569 clinical bone sonometer (Hologic, Inc, Waltham, MA) . To ensure accuracy, this device was calibrated daily using the manufacturer-provided phantom before data collection, following standard protocols as described previously[16, 29, 30]. The coefficient of variation (CV) for repeated measures was within the acceptable range, ensuring consistency. The Sahara Clinical Bone Sonometer automatically used the values of the SOS (m/s) and BUA (dB/MHz) to compute the Quantitative Ultrasound Index (QUI) and the estimated Bone Mineral Density (eBMD, in g/cm2) using the equation: QUI = (0.67 9 BUA) + (0.28 9 SOS) - 420 and eBMD = 0.002592 x (BUA + SOS) – 3.687. Further details of these procedures as used in this study have been described in detail, elsewhere [16].

Assessment of the biochemical marker- serum calcium.

Serum calcium measurements comprise the ionized calcium (Ca2+) and total body calcium (CaT) measurements. The serum calcium assay was done using a standard technique called Ion Selective Electrode (ISE) technique to determine the values of (Ca2+) and (CaT) and the equipment used was a PERLONG (PL1000A; Serial number: EBAAGA69010A) automatic Electrolyte analyzer. This instrument underwent routine calibration and quality control checks using standard reference solutions before each batch of analysis. The analytical error margin for serum calcium measurement was within ±0.1 mmol/L, which is within the acceptable range for clinical and research settings. The participant's blood sample was collected from the antecubital vein of each participant by venipuncture technique according to standard protocols, without a tourniquet into a container. A 2ml syringe was used to draw about 2ml of blood. The blood sample collected was dispensed in a dry clean sample tube and was allowed to clot. The sample tube was then put in a centrifuge and spun at a high speed for 5 minutes.

Thereafter, the serum was put into a separate tube for analysis.

Statistical Analysis

Data were categorized according to the age, sex, and BMI of the participants. The children were grouped into nine age groups. The demographic variables were reported as percentages, whereas BMI, QUI, eBMD, and serum calcium were presented as means ± standard deviations. Comparisons between boys and girls were conducted using an independent sample t-test. One-way analysis of variance (ANOVA) was used to compare QUI and eBMD values by sex and age, with Bonferroni post hoc tests applied for multiple comparisons. Pearson correlation coefficients were calculated to determine the relationships between age, sex, BMI, serum calcium, QUI, and eBMD. To further explore the predictive factors for QUI and eBMD, a multiple regression model was employed. Prior to conducting these analyses, the assumptions of normality, homoscedasticity, and multicollinearity were assessed. Normality was evaluated using Shapiro-Wilk tests, histograms, and Q-Q plots, confirming no significant deviation from normal distribution. Homoscedasticity was verified by inspecting the residual plots, which showed a random pattern indicative of constant variance. Multicollinearity was assessed using Variance Inflation Factor (VIF) and tolerance values, with all VIF values remaining below 10 and tolerance values above 0.1, indicating no significant multicollinearity concerns. All statistical analyses were performed using SPSS version 23.0 (IBM Corporation, Armonk, NY), with a significance level set at $p < 0.05$.

RESULTS:

Figures 1 and 2 show the age and sex distribution of the participants, respectively.

The sex- and age-specific mean values of the QUS parameters are presented in Table 1. The highest eBMD and QUI values occurred in the 11-year age group for both the boys and girls. When both genders were compared, there was a statistically significant difference ($p < 0.05$) in the mean QUI and eBMD between the boys and girls of 10, 12, and 13 years. There was no statistically significant difference between the boys and the girls in all the mean QUS parameters in the rest of the age groups. The mean QUI of the 7 years age group was significantly different from those of 11 years, 12 years, and 13 years. The mean eBMD of the 6- and 7-year age groups were significantly different from those of 11 years, 12 years, and 13 years. The mean QUI of the 6 years age group was also significantly different from those of 14 years. The mean eBMD of the 8 years age group was significantly different from those of 14 years.

Table 2 shows the Serum calcium measurements of the study population comparison by gender. The ionic calcium values for boys were noted to be lower than that of the girls between the ages of 6-8 years with a significant difference in the 8 years' age group ($p = 0.03$); however, that of the boys became higher than that of the girls from 9-14 years with a significant difference in the 12 years age group ($p = 0.02$). A similar trend was seen in the Total calcium values between the boys and girls across the different ages though there was no significant difference between the boys and girls in any of the age groups. Table 3 shows the correlation between QUS parameters, age, BMI, and serum calcium by gender. In both genders, age, and BMI had positive significant associations with the QUI and eBMD. Both total and ionic serum calcium had no association with the two QUS parameters in both genders. Table 4 presents multiple regression analysis to determine the relationship between the calcaneal QUS, age, and the BMI by gender. In both genders, age was seen as a predictor of both QUI and eBMD while BMI was the predictor of QUS in only the girls.

Table 1: Reference Baseline Values of QUS Parameters QUI AND eBMD by age, gender, and BMI

AGE (years)	Boys				Girls			
	N	BMI (Kg/m^2) Mean ± SD	QUI Mean ± SD	eBMD (g/cm^2) Mean ± SD	n	BMI (Kg/m^2) Mean ± SD	QUI Mean ± SD	eBMD (g/cm^2) Mean ± SD
6	23	15.57 ± 2.06	87.33±11.28[a]	0.48±0.0 07[a]	25	16.15 ± 2.44	86.07±10.37[a]	0.47±0.07[a,b]
7	25	15.80 ± 1.37	86.54±13.13[a]	0.47±0.08[a]	19	15.89 ± 2.51	85.78±16.66[a,b]	0.47±0.10[a.b]
8	26	16.39 ± 2.52	90.22±12.16[a,b]	0.49+0.07[a,b]	30	16.33 ± 3.29	87.17+12.23[a,b]	0.47+0.08[a]
9	34	16.21 ± 1.78	91.93±13.33[a,b]	0.51±0.08[a,b]	37	15.59 ± 1.68	91.84±15.74[a,b]	0.50±0.10 [a,b]
10	39	15.95 ± 1.28	94.76±13.95*[a,b]	0.52±0.09*[a,b]	31	16.31 ± 2.49	87.88±12.21*[a,b]	0.48±0.08*[a,b]
11	51	16.20 ± 1.78	98.52±12.46[b]	0.54±0.08[b]	59	17.26 ± 2.22	95.95±14.87[a,b]	0.53±0.10 [a,b]
12	91	16.84 ± 2.09	97.62±13.99*[b]	0.54±0.07*[b]	100	17.53 ± 2.20	92.41±12.54*[a,b]	0.51±0.09* [a,b]
13	120	17.27 ± 1.78	96.95±12.42*[b]	0.53±0.08*[b]	123	18.68 ± 2.49	93.12±11.88*[a,b]	0.51±0.07* [a,b]
14	85	17.75 ± 1.85	94.18±13.20[a,b]	0.52±0.08[a,b]	98	19.53 ± 2.39	95.79±13.75[b]	0.53±0.09 [b]
Total	494	16.79 ± 1.97	94.91±13.37*	0.52±0.08*	522	17.74 ± 2.70	92.46±13.47*	0.51±0.09*

*Statistically significant difference between boys and girls ($P < .05$) for QUI and eBMD values only

a,b,cSignificant differences across the ages for the boys. a,b,c,dSignificant differences across the ages for the girls. Means with the same letter did not differ significantly from each other by age according to the Bonferroni multiple-comparison test done separately among the boys and girls. Height and weight measurements of the subjects have been mentioned elsewhere (16).

Table 2: Serum calcium measurements of the study population comparison by Gender

Age(Years)	Boys Mean ± SD	Girls: Mean ± SD	p-Value
	Ionic Ca2+(mmol/l)		
6	0.98 ± 0.09	0.99 ± 0.12	0.80
7	0.91 ± 0.10	0.94 ± 0.13	0.44
8	0.92 ± 0.12	0.99 ± 0.12	0.03*
9	0.98 ± 0.07	0.95 ± 0.15	0.27
10	1.00 ± 0.11	0.99 ± 0.10	0.49
11	1.03 ± 0.12	1.02 ± 0.11	0.51
12	1.05± 0.13	1.01 ± 0.13	0.02*
13	1.03 ± 0.13	1.01 ± 0.10	0.16
14	1.03 ± 0.13	1.01 ± 0.11	0.31
Total	1.02 ± 0.13	1.00 ± 0.12	0.06
	Total Ca (mmol/l)		
6	2.25 ± 0.26	2.28 ± 0.25	0.75
7	2.16 ± 0.25	2.18 ± 0.25	0.75
8	2.18 ± 0.22	2.26 ± 0.27	0.24
9	2.20 ± 0.21	2.19 ± 0.29	0.85
10	2.28 ± 0.20	2.25 ± 0.22	0.54
11	2.24 ± 0.21	2.22 ± 0.23	0.56
12	2.28 ± 0.23	2.26 ± 0.25	0.43
13	2.31 ± 0.22	2.29 ± 0.21	0.56
14	2.31 ± 0.24	2.32 ± 0.23	0.61
Total	2.27 ± 0.23	2.27 ± 0.24	0.81

*$p<0.05$

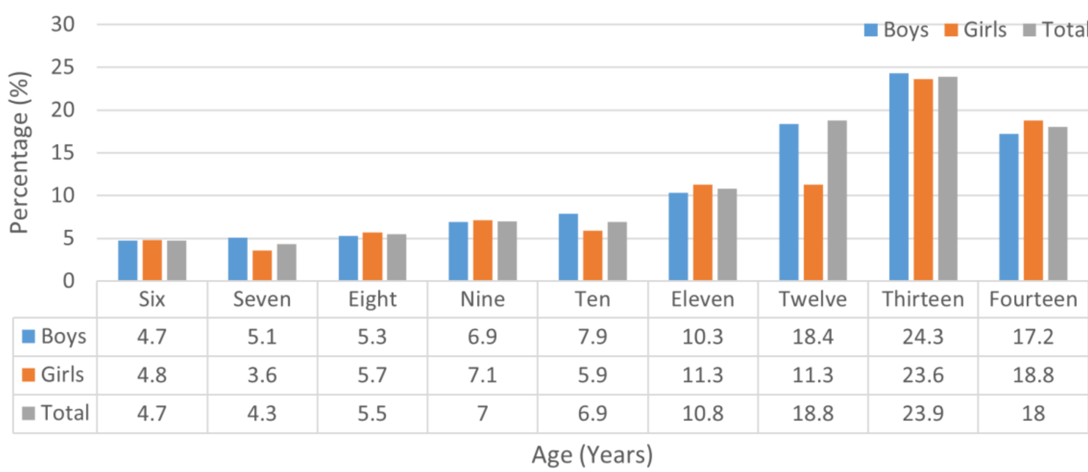
Table 3: Pearson's correlation between QUS parameters, age, BMI, and Serum calcium by gender

	Boys				**Girls**			
Variable	**QUI**	**p-value**	**eBMD**	**p-value**	**QUI**	**p-value**	**eBMD**	**p-value**
Age of respondents	0.185†	< 0.001	0.187†	< 0.001	0.193†	< 0.001	0.194†	<0.001
BMI (kg/m^2)	0.097*	0.032	0.105*	0.019	0.222†	< 0.001	0.214†	<0.001
Ionic Calcium (mmol/l)	0.060	0.180	0.066	0.144	0.041	0.350	0.045	0.303
Total calcium (mmol/l)	0.066	0.143	0.070	0.119	0.016	0.709	0.014	0.747

Table 4: Multiple regression analyses with QUI and eBMD as dependent variables and Age and BMI as independent variables.

QUI				
Variable	**BOYS §R^2= 0.032**		**GIRLS §R^2= 0.057**	
	B	P	B	P
Age	0.991	<0.001	0.700	0.012
BMI	0.288	0.364	0.846	<0.001
eBMD				
Variable	**BOYS §R^2= 0.034**		**GIRLS §R^2= 0.055**	
	B	P	B	P
Age	0.006	<0.001	0.005	0.009
BMI	0.002	0.273	0.005	0.001

B: Unstandardized regression coefficients; §R^2: Adjusted R square; QUI: Quantitative Ultrasound index; eBMD: Estimated bone mineral density p-values < 0.05= significant



	Six	Seven	Eight	Nine	Ten	Eleven	Twelve	Thirteen	Fourteen
Boys	4.7	5.1	5.3	6.9	7.9	10.3	18.4	24.3	17.2
Girls	4.8	3.6	5.7	7.1	5.9	11.3	11.3	23.6	18.8
Total	4.7	4.3	5.5	7	6.9	10.8	18.8	23.9	18

Figure 1: Age Distribution of Children by Percentage. The percentage distribution of boys, girls, and the total population across various age groups (6–14 years). As age increases, the percentage of both boys and girls increases, peaking at age 13, where boys make up 24.3% and girls 23.6% of the population. The total percentage is highest at age 13 (23.9%) before slightly declining at age 14. Overall, the chart demonstrates a trend of increasing representation with age, with a slight drop after the peakFigure 1: Impact of the challenges on the effectiveness and quality of radiography training (n = 14)

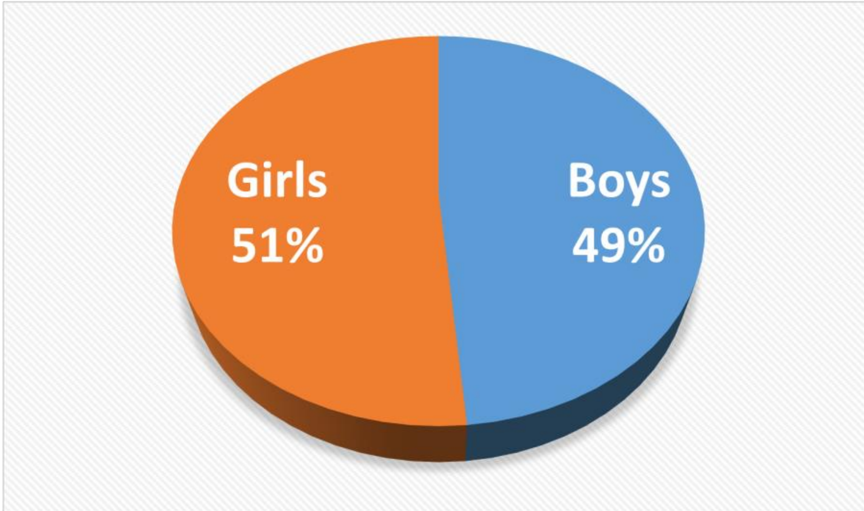


Figure 2: Gender Distribution of the participants. The 3D pie chart illustrates the overall gender distribution of the participants, with girls representing 51% and boys representing 49%. The proportions show an almost equal split between the two genders, with a slight but not significant majority for girls

DISCUSSION

Calcaneus QUS measurement is known as a key research instrument for identifying low bone mass in the pediatric population [8]. To the best of the researchers' knowledge, no study has established age- and sex-dependent reference values for the calcaneal QUI and eBMD in healthy Nigerian children population using the Hologic QUS sonometer. This cross-sectional study has achieved this in 494 boys and 522 girls of Nigerian origin, aged 6 to 14 years, and in addition, investigated the influence of BMI and Serum calcium on these calcaneal QUS parameters. The previously published Calcaneal QUS baseline reference values for Nigerian children were only for the BUA and SOS (16). In addition to determining bone density, the QUI and eBMD which are the composite indices of BUA and SOS, are suggested by some researchers, to be more useful in the determination of subjects with low bone health status [31, 32]. The findings of this study provide an important understanding of bone health in Nigerian children, which could serve as a foundation for other future studies and healthcare interventions.

Our findings showed the mean QUI and eBMD (SD) of the subjects to be 94.91 (13.37) and 0.52 (0.08) g/cm^2, respectively, for boys and 92.46 (13.47) and 0.51 (0.09) g/cm^2 for girls. When compared with other age-matched world populations, the QUI values in our study were higher than those of a Chinese age-matched population [21]. This, however, may not be relied upon as the difference may be due to the different sonometers used in the studies and different sample sizes. This observed differences in QUI values between Nigerian and Chinese children are influenced by multiple factors beyond differences in ultrasound devices. Genetic predisposition, dietary calcium intake, vitamin D status, physical activity levels, and pubertal timing all contribute to population-specific bone mineralization patterns. While device calibration differences may play a minor role, the larger biological and environmental determinants provide a more comprehensive explanation for the observed variations.

Age and Gender Differences in the QUS Parameters

The study revealed age-related differences in bone mineral density (in both the boys and girls), with older children, especially those in the 11-14 age group, having higher QUI and eBMD values compared to younger children. The ages with the highest QUI and eBMD values were 11 years for the boys while for the girls were 11 and 14 years. Similar studies show children experience notable increases in BMD during their pre-pubertal as well as early adolescent stages. During these stages, the values of QUI and eBMD are observed to record a sharp rise which reflects increased bone mineralization as skeletal growth accelerates [21, 33, 34, 35]. These findings are in line with the natural process of bone accrual during growth and development, predominantly during the prepubertal and early pubertal years, when bone formation overtakes resorption [12]. Boys had slightly higher bone density values than girls, although the differences were not statistically significant across all age groups. These gender differences may reflect the influence of sex hormones on bone metabolism during puberty [9].

The relationship between BMI and the QUS parameters

Studies including those done using DEXA [36-38], have linked higher BMI in children with increased bone mass because of the additional mechanical load that body weight places on bones, which can encourage bone formation. Several other studies have also explored the relationship between BMI and bone health parameters like QUI and eBMD [21, 34, 35]. These studies find a significantly positive relationship between BMI and bone density parameters in children of both genders, especially during growth stages when bone mass is rapidly accumulative. For example, a cohort study involving children aged 6 to 16 years found that higher BMI was significantly associated with greater bone density as measured by QUI and eBMD. This positive relationship was especially noted as strongest during pre-pubertal and pubertal growth spurts [34]. Our study had an interesting finding as BMI was a predictor of QUI and eBMD only in girls. The gender-specific relationship between BMI and the QUS parameters, noted in our study, can be explained by hormonal influences (estrogen), differences in fat distribution, puberty stage, physical activity levels and lifestyle factors. These factors create a stronger correlation between BMI and bone health in girls, while boys' bone development is more influenced by muscle mass and physical activity [34, 35, 39]. Estrogen, for instance, is impactful for girls and increases with fat mass. It promotes the mineralization of bones and the retention of calcium, which could explain the higher bone density in girls with greater BMI. On the other hand, boys' bone density tends to be impacted more by muscle mass and mechanical loading, which here is driven by testosterone instead of BMI [40, 41]. Girls enter puberty earlier, leading to faster bone mineral accrual compared to boys, who have a delayed but stronger growth spurt [15]. This could make BMI a more significant predictor of bone density in girls than in boys. Additionally, boys typically engage in higher-impact physical activities that naturally stimulate bone strength. Girls, with generally lower weight-bearing activity levels, may rely more on body weight (BMI) as a determinant of bone health [34]. Since BMI reflects both fat and muscle, the association in girls may be due to adipose tissue's role in estrogen production rather than mechanical bone stimulation. Higher calcium intake, vitamin D status, and lifestyle choices could also contribute to this gender difference. While serum calcium levels were not significant predictors of QUI and eBMD in this study, unmeasured factors such as dietary calcium intake and physical activity levels may have influenced the results [42]. Worth of note here, is the fact that our study controlled for age and serum calcium levels to isolate BMI's effect on bone health. However, hormonal levels, physical activity, pubertal status, and vitamin D levels were not included, which may have influenced the findings. Future research should incorporate these variables for a more comprehensive analysis and to further understand this sex-based difference in bone health.

Gender Differences in Serum Calcium

The study shows that girls have higher ionic calcium levels than boys in the earlier age groups, particularly at age 8 ($p = 0.03$). This is consistent with findings from previous research, which associated differences in calcium metabolism with hormonal and physiological changes during preadolescence in girls [40]. When girls undergo earlier pubertal development, with increased estrogen levels, studies suggest this enhances calcium absorption and retention in bones during these early years. In contrast to the above finding from our study, boys in our study tend to have a significantly higher ionic calcium level than girls from age 9 onwards ($p = 0.02$). This could be due to the delayed but more distinct growth spurt in boys during puberty, with increased levels of testosterone, which may affect calcium metabolism and bone mineralization.

Testosterone has been noted to stimulate bone growth and calcium uptake, contributing to these observed differences during adolescence [41]. While the study noted variations in ionic calcium levels between boys, the total calcium levels remain relatively stable, with no significant gender differences in any of the age groups (p> 0.24). This finding is consistent with research indicating that overall calcium homeostasis is firmly regulated by hormones like parathyroid hormone (PTH), vitamin D, and calcitonin, which work to maintain stable serum calcium levels irrespective of age or gender [43]. Other studies have also found no significant differences in total serum calcium between genders during childhood and adolescence [14, 44].

The relationship between serum calcium and the QUS parameters

There have been seemingly varying reports on the relationship between serum calcium and BMD. While some studies had reported that serum calcium plays a crucial role in determining bone mineral density in children, [45-48], others [49, 50], including the finding of this study, showed that serum calcium had no significant correlation with the QUS parameters studied. These studies emphasize the complexities of calcium's role in bone health, particularly when combined with other bone-affecting factors like BMI, vitamin D, and age [39]. We suggest possible reasons for our findings being that if there is Vitamin D deficiency among the children as is prevalent in many parts of Africa, calcium absorption and bone health might be affected despite normal serum calcium levels. Other factors that may have affected the findings could be genetic variability, bone density variations, socio-economic and environmental factors, etc. The lack of a relationship between serum calcium and QUI and eBMD in this study may suggest that bone health is influenced by a blend of factors apart from serum calcium levels. This finding emphasizes the need for the use of a multifaceted approach to assessing and addressing bone health in children. Again, while the study accounted for some confounding variables, the lack of data on dietary calcium intake, vitamin D status, and genetic markers limits the ability to draw definitive conclusions. Future research should, therefore, incorporate nutritional assessments, vitamin D measurements, and genetic studies to provide a more comprehensive understanding of the factors influencing bone mineralization in Nigerian children populations as well as consequently develop targeted interventions.

Despite the strengths and valuable insights provided by this study, it was not without limitations. Firstly, this study was limited to Enugu State, Nigeria, and may not fully represent the entire Nigerian pediatric population due to potential regional differences in bone health factors. While our sample included diverse socio-economic backgrounds, broader studies across multiple geopolitical zones are needed for nationwide reference values. Secondly, the ability to establish causal relationships between BMI, serum calcium, and bone health parameters may have been somewhat restricted because it was a cross-sectional design. A longitudinal study involving a much larger population from all the geographical zones of the country would be more suitable to determine the long-term effects of these variables on bone mineral density (BMD), as well as strengthen the use of the QUI and eBMD as reference values. Another limitation is the absence of Vitamin D measurement, which is vital for calcium absorption and bone health. Although the study suggested the lack of a relationship between serum calcium and bone health to be due to Vitamin D deficiency, this hypothesis may not be fully explored as Vitamin D levels measurement was not part of the study. Furthermore, the lack of data on pubertal status is another limitation. As the study notes, hormonal changes during puberty significantly influence bone mineral density, but without accounting for the pubertal stage, it is difficult to assess the full impact of age and sex on the QUS parameters.

In conclusion, this study provides valuable reference baseline values for QUI and eBMD in Nigerian children and highlights the influence of BMI on bone density. The findings also beg for more research, having raised significant concerns regarding the function of serum calcium in the bone health of children. These results contribute to a better understanding of bone health in Nigerian children and underscore the need for early interventions to promote bone strength and reduce the risk of osteoporosis later in life. Further studies on these QUS parameters, involving a larger number of Nigerian children are recommended to help establish more robust reference values.

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