



ORIGINAL ARTICLE

Ultrasound reference values for the calcaneus of children and adolescents at moderate altitudes in Peru<sup>☆</sup>



Rossana Gómez-Campos <sup>a</sup>, Jose Sulla-Torres <sup>b</sup>, Cynthia Lee Andruske <sup>c</sup>, Luis Felipe Castelli Correia de Campos <sup>d</sup>, Cristian Luarte-Rocha <sup>e</sup>, Wilbert Cossio-Bolaños <sup>f</sup>, Marco Antonio Cossio-Bolaños <sup>g,\*</sup>

<sup>a</sup> Universidad Católica del Maule, Department of Diversity and Educational Inclusiveness, Talca, Chile

<sup>b</sup> Universidad Católica de Santa María, Arequipa, Peru

<sup>c</sup> Center for Research, CINEMAROS, Arequipa, Peru

<sup>d</sup> Universidad del Bio Bio, Chillán, Chile

<sup>e</sup> Universidad San Sebastián, Concepción, Chile

<sup>f</sup> Universidad Privada San Juan Bautista, Lima, Peru

<sup>g</sup> Universidad Católica del Maule, Doctorate Program in Physical Activity Sciences, Talca, Chile

Received 2 October 2019; accepted 23 December 2019

Available online 19 February 2020

KEYWORDS

Bone parameters;  
Ultrasound of the  
calcaneus;  
Percentiles

Abstract

**Objective:** a) Establish reference values for bone parameters by using the speed of sound (SOS, m/s) of broadband ultrasound attenuation (BUA, dB/MHz) and establish a bone quality index (BQI =  $\alpha$ SOS +  $\beta$ BUA) for children and adolescents living in a region of moderate altitude, b) compare bone parameters with an international standard (with different ethnic, socio-economic, and lifestyle backgrounds) by using ultrasound of the calcaneus (heel bone) (QUS).

**Methods:** A descriptive cross-sectional study was carried out with children and adolescents between the ages of 6.0 and 16.9 years old. The sample was selected randomly. A total of 1322 subjects were studied. Weight, height, and bone parameters, using ultrasound of the calcaneus, were evaluated SOS, BUA, and BQI. Body Mass Index BMI was calculated.

**Results:** The average age of males was  $11.44 \pm 0.35$  years old, and for females, it was  $11.43 \pm 0.35$  years old. The students in this research showed slightly higher values of SOS, BUA, and BQI for both sexes when compared with the international reference (the 50th percentile). Percentiles were generated (P3, P10, P25, P50, P75, P90, and P97) using the LMS method [median (M), standard deviation (S), and power of the Box-Cox transformation (L)] by age and sex.

<sup>☆</sup> Please cite this article as: Gómez-Campos R, Sulla-Torres J, Andruske CL, Campos LF, Luarte-Rocha C, Cossio-Bolaños W, et al. Ultrasound reference values for the calcaneus of children and adolescents at moderate altitudes in Peru. J Pediatr (Rio J). 2020;97:88–95.

\* Corresponding author.

E-mail: [mcossio1972@gmail.com](mailto:mcossio1972@gmail.com) (M.A. Cossio-Bolaños).

**Conclusion:** The students living at a moderate altitude showed slightly higher values in bone parameters in relation to the international reference. This pattern depicted a population with a better state of bone health. The proposed percentiles may be used to categorize adequate to at risk bone parameters based on age and sex.

© 2020 Published by Elsevier Editora Ltda. on behalf of Sociedade Brasileira de Pediatria. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

## Introduction

Assessment of bone health is becoming more important in today's world. Bone mass with a high peak value appears to diminish the risk of future osteoporosis.<sup>1</sup>

In general, environmental risk factors are crucial in developing osteoporosis since typically they are associated with a Western lifestyle, characterized by low levels of physical activity, and deficient diets that include processed foods, such as coffee and carbonated drinks. In addition, a number of congenital or acquired diseases also affect bone development and growth during childhood and adolescence.<sup>2</sup>

In fact, the gold standard method for diagnosing osteoporosis recommended by the World Health Organization (WHO) is the dual X-ray absorptiometry (DXA) method.<sup>3</sup> However, the quantitative ultrasound (QUS) is widely considered to be a fast, economical alternative means of evaluation without the use of radiation. Moreover, it is highly portable for evaluating bone health in large populations.<sup>4–6</sup>

QUS evaluates parameters commonly generated for the calcaneus. These are derived from the following measures: speed of sound (SOS, m/s), wide band ultrasound attenuation (BUA, dB/MHz); and bone quality index (BQI =  $\alpha$ SOS +  $\beta$ BUA,  $\alpha$  $\beta$ : temperature corrections). These parameters are recognized as determinant measures of the health status of the calcaneus in terms of the micro-architecture and bone mineral density (BMD).<sup>3</sup> Thus, in the past few years, the use of the QUS technology has increased. This has been used in a number of research studies carried out with samples of children and adolescents in diverse regions of the world.<sup>6–9</sup> These findings reflect ethnic differences between populations.

As a result, the lack of information about BMD in populations living at a moderate altitude and, especially, countries under development, like Peru, need to be studied. Thus, as far as we know, no research exists about bone health of students living in regions of moderate and high altitudes.

This gap in the literature limits the ability of health professionals and others to evaluate the prevalence and the risk of osteoporosis during the early ages. This lack of knowledge complicates prevention efforts and developing intervention programs for the groups in most need, especially students during the development and growth periods.

In general, researchers studying groups living at moderate altitudes in Peru<sup>10</sup> and Columbia<sup>11</sup> are affected by decreased physical growth patterns when compared with international references. Furthermore, the positive changes observed in secular physical growth trends and body adipos-

ity of students living at moderate altitudes in Peru,<sup>12</sup> and the increase in food intake during the past few years in 14.8%<sup>13</sup> of the Peruvian population may influence the bone parameters of children and adolescents living at a moderate altitude in Peru (2,320 meters above sea level).

Therefore, the objectives of this research study include: a) establish reference values for bone parameters using the speed of sound (SOS, m/s), Broadband ultrasound attenuation (BUA, dB/MHz); and the bone quality index (BQI =  $\alpha$ SOS +  $\beta$ BUA) for children and adolescents living in a region of moderate altitude in Peru, and b) compare bone parameters with an international standard (with different ethnic, socio-economic, and lifestyle backgrounds) by using ultrasound of the calcaneus (heel bone) (QUS).

## Methods

### Type of study and sample

A descriptive cross sectional study was carried out with children and adolescents between the ages of 6.0 and 16.9 years old. The sample population was composed of 10,502 subjects 5,209 males and 5,293 females. The sample was selected randomly. Twelve percent of the sample consisted of 1322 subjects [620 (5.9%) males and 702 (6.7%) females, IC: 95%]. This included 6 schools from the province of Arequipa, Peru (moderate altitude). The average age for males was  $11.44 \pm 0.35$  years, and for females, it was  $11.43 \pm 0.35$  years.

Arequipa is located at 2,320m above sea level (moderate altitude). Relative humidity during the year is between 46% and 70%, and the temperature varies between 10° to 25 °C.<sup>14</sup> This city is considered to be an example of development for the country, particularly in industry, agriculture, and commerce. The Human Development Index (HDI) for Peru in 2013 was 0.741, and for Arequipa, it was 0.745.<sup>15</sup>

Criteria for including subjects in this study were that the individuals needed to be students registered in a state school. Students also needed to be from elementary (ages 6.0–11.9) or secondary school (12.0–16.9 years old) to be included in the study. Additionally, the schools and students needed to belong to urban areas of the province of Arequipa (Peru). Students excluded included those with a sports injury on the right foot and at the time of the evaluation took any kind of medication (n = 34 subjects).

The research was carried out in keeping with the Declaration of Helsinki for Human Subjects. Ethical approval was obtained from the Research and Ethics Committee from Universidad Católica Santa María (2017).

## Procedures

Data collection took place at each school. A small laboratory was prepared and equipped in order to collect and evaluate the variables for the study. Initially, the anthropometric variables were collected, and, afterwards, the bone parameters were taken (a scan of the right foot). The evaluations took place between April and July of 2017 and 2018 during school hours (8:00 a.m. to 13:00 p.m.).

To evaluate weight and height, the protocol developed by Ross and Marfell-Jones<sup>16</sup> was followed. The anthropometric variables were collected with the students barefoot and the least amount of clothing possible (shorts and a T-shirt). Students were weighed with a Tanita (United Kingdom, Ltd.) digital scale with an accuracy of 0.1 kg. Standing height was measured with a portable stadiometer (Hamburg, Seca, Ltd.) with an accuracy of 0.1 mm according to the Plane of Frankfurt. Body Mass Index (BMI) was obtained from weight and height. The formula proposed by Quetelet [ $BMI = \text{weight (kg)}/\text{height (m)}^2$ ] was used to calculate the BMI.

Using ultrasound scans (QUS), the bone parameter measurements of the calcaneus were recorded using a bone densitometer SONOST 3000 (Seoul, South Korea). The parameters measured with the QUS included the following: the speed of sound (SOS, m/s), wide broadband ultrasound attenuation (BUA, dB/MHz), and the bone quality index ( $BQI = \alpha \text{SOS} + \beta \text{BUA}$ ,  $\alpha, \beta$ : temperature correction). The evaluation of each subject lasted 15 s. The entire procedure was carried out by one trained evaluator with significant experience. Ten percent of the sample was evaluated two times ( $n = 120$ ). The intra-evaluator Technical Error of Measurement (TEM) was 1.2%.

## Statistics

The Kolmogorov-Smirnov (K-S) test was used to verify the normality of the data. Afterwards, descriptive statistical analysis (arithmetic mean, standard deviation, and range) was carried out. To determine the differences between both sexes, the student *t*-test for independent samples was used. Z-scores were calculated with the goal of comparing data from weight, height, and body mass index of the students from the present study with the normative references established by the CDC-2012. The following equation was used to calculate the Z-scores:  $Z = [(X/M) - 1]/L * S$ , where X was the measure observed (weight, height, and BMI) for each subject; M the median, L the asymmetry value, -1 the constant, and S the coefficient of variation. The L, M, and S values were obtained from the normative tables from the CDC-2012. When the L, M, and S values were not available, the Z-score was used:  $Z = (X - M)/SD$ , where X is the observed value, M the average, and SD the standard deviation. M and SD were obtained from the CDC-2012 reference for age and sex.

The LMS<sup>17</sup> statistical method was used to create reference curves for bone parameters for children and adolescents living at a moderate altitude in Peru (BQI, SOS, and BUA) based on age and sex. The following percentiles were calculated: p3, p10, p15, p25, p50, p75, p85, p90, and p97. LMS was used to estimate three parameters: LMS [median (M), standard deviation (S), and power of the Box-Cox trans-

formation (L)]. These three parameters were based on the function of age.

The comparisons of the percentiles between both sexes studied were carried out by plotting the 50th percentile. LMS Chartmaker Pro version 2.3<sup>18</sup> and SPSS for Windows v. 20 (SPSS Inc., Chicago, IL) software were used. In all cases,  $p < 0.05$  was adopted.

## Results

The variables for weight, height, and BMI by age are illustrated in Table 1. The anthropometric variable values increased as age advanced from 6.0 to 16.9 years old. In general, no significant differences occurred in weight and height between the sexes. Values were similar until age 14.9 years old. On the contrary, during the last two ages (15.0–16.9), males weighed more, and they were taller in comparison to the females ( $p < 0.05$ ). With regard to BMI, no differences were observed in both sexes at any age range ( $p > 0.05$ ).

The prevalence of overweight in males was 7.6%. For females, 4.4% were found to be overweight.

With regard to comparisons for the weight, height, and BMI variables between children and adolescents living in a region of moderate altitude and the CDC-2012 references based on Z-scores, the results for weight presented lower values than the CDC-2012 average. Negative Z-score values ranged between -0.14 to -0.72 for males ages 11.0–16.9 and -0.32 to -0.71 for females 10.0–16.9 years old. In addition, the values were similar between ages 6.0 and 9.9 years for both sexes.

The results for height represented a lower value than the CDC-2012 average. Negative Z-scores occurred at all ages. These varied from -0.14 to -1.50 for males, and for females, Z-scores varied from -0.21 to -1.05.

On the contrary, at early ages, BMI Z-score values were higher. From age 13.0 years, lower values were observed in both sexes. In general, children and adolescents living at a moderate altitude showed lower weight and height in comparison to the international reference.

The percentile distribution by age and sex for the SOS, BUA, and BQI is illustrated in Tables 2 and 3. In all cases, values rose slightly as age advanced.

Comparison of the bone parameters of this present research study conducted in Arequipa (Peru) and those in Hungary are graphically illustrated in Fig. 1. Comparisons began commencing with percentile 50 (LMS) for all of the age ranges.

The children and adolescents from Arequipa presented higher SOS values than those for the reference group from Hungary. The SOS values were higher for males: 17.8–39.5 m/s, and for females: 47.7–69.5 m/s. For the BQI, males and females from Arequipa showed higher values in relation to the Hungarian reference. These values were greater for males starting from 29.7 to 40.3 and for females from 19.1 to 29.3, respectively. These comparisons were calculated mathematically.

With regard to the broadband ultrasound attenuation (BUA), the females from Arequipa showed higher values in all age ranges when compared with the international reference, except for age 16.9 years old. At this age, the values were similar. Elevated values began at 1.7–14.5 (dB/MHz). How-

**Table 1** Anthropometric characteristics and Body Mass Index of children and adolescents studied.

Age (years)	n	Weight (kg)		Height (cm)		BMI (kg/m <sup>2</sup> )		Weight Z-score		Height Z-score		BMI Z-score	
		X	SD	X	SD	X	SD	X	SD	X	SD	X	SD
<b>Males</b>													
6.0–6.9	78	24.30	4.90	117.90	6.40	17.30	2.30	.00	.75	−.22	1.01	.12	.65
7.0–7.9	75	28.10	5.60	124.50	4.90	18.10	2.90	.23	.89	−.14	.78	.37	.94
8.0–8.9	66	32.00	7.00	129.40	5.20	19.00	3.30	.07	.69	−.23	.54	.28	.85
9.0–9.9	62	35.50	8.20	134.30	6.90	19.50	3.60	−.07	.51	−.29	.56	.42	.93
10.0–10.9	64	39.40	10.10	139.30	6.10	20.20	4.70	−.04	.77	−.33	.68	.13	.96
11.0–11.9	58	44.40	9.80	144.90	5.80	21.00	4.70	−.14	.59	−.55	.64	.10	.78
12.0–12.9	51	48.70	12.20	150.40	7.50	21.30	4.10	−.17	.76	−.55	.97	.01	.75
13.0–13.9	47	52.10	11.00	156.20	8.40	21.20	3.40	−.41	.64	−.91	1.02	−.12	.59
14.0–14.9	44	56.90 <sup>a</sup>	11.30	161.50 <sup>a</sup>	8.40	21.70	3.50	−.27	.44	−.58	.67	−.09	.44
15.0–15.9	43	58.20 <sup>a</sup>	9.90	164.20 <sup>a</sup>	7.20	21.50	3.10	−.48	.40	−.87	.65	−.22	.44
16.0–16.9	32	60.70 <sup>a</sup>	10.70	165.20 <sup>a</sup>	6.80	22.20	3.70	−.72	.53	−1.50	1.03	−.36	.57
Total	620	43.66 <sup>a</sup>	9.15	144.35 <sup>a</sup>	6.69	20.27	3.55	−.25	.68	−.67	.92	.00	.72
<b>Females</b>													
6.0–6.9	87	23.20	5.00	115.40	6.80	17.30	2.80	−.06	.80	−.55	.98	.25	.86
7.0–7.9	78	28.50	17.30	122.40	5.50	17.70	3.00	.02	.69	−.28	.72	.22	.72
8.0–8.9	82	30.20	6.50	128.50	6.70	18.20	2.80	−.12	.45	−.21	.56	.30	.78
9.0–9.9	78	34.40	8.00	133.70	6.10	19.10	3.70	−.08	.57	−.49	.91	.07	.59
10.0–10.9	81	37.70	8.90	139.80	6.00	19.20	4.10	−.34	.89	−.67	.86	−.08	1.07
11.0–11.9	78	45.40	8.10	145.80	6.30	21.30	3.60	.43	.81	.18	.89	.49	.95
12.0–12.9	54	46.40	8.30	150.40	5.90	20.50	3.10	−.36	.51	−.70	.71	−.13	.49
13.0–13.9	50	51.50	7.90	153.20	5.20	21.90	3.00	−.32	.47	−1.05	.80	−.03	.50
14.0–14.9	44	51.20	8.60	154.10	5.50	21.50	3.20	−.71	.59	−.76	.56	−.39	.62
15.0–15.9	40	54.00	8.50	156.00	6.10	22.20	4.00	−.61	.53	−.69	.58	−.36	.53
16.0–16.9	30	54.40	8.10	156.80	5.70	22.00	3.00	−.57	.59	−.68	.71	−.32	.61
Total	702	41.54	8.65	141.46	5.98	20.09	3.30	−.28	.68	−.56	.81	−.04	.75

X, average; SD, standard deviation; BMI, body mass index.

<sup>a</sup> p < 0.05.

ever, for males, the pattern of higher values was maintained until age 13.9 years old, and later the attenuation diminished drastically to −1.9 to −4.8 dB/MHz until age 14.0. At 16.0 years old, the values resembled the international reference.

## Discussion

The researchers of this study proposed percentiles to evaluate the bone health of children and adolescents living at a moderate altitude. The quantitative ultrasound technique was used to analyze bone micro-structures, BMD of the calcaneus (heel bone),<sup>5</sup> and bone elasticity.<sup>19</sup>

The calcaneus is the site most commonly used in the skeleton for ultrasound.<sup>20</sup> It represents 95% of the trabecular bone and is composed of two lateral surfaces that facilitate the use of the ultrasound.<sup>3</sup>

In this sense, a number of studies used bone parameters (BUA, SOS, and BQI) to report values in percentiles. The results from those studies coincide with the results described in this current study, organized based on age and sex.<sup>2,6,9,21</sup> Furthermore, the maximum bone mass is reached between the ages of 16.0–18 years old in both sexes, and they are similar to those in studies cited previously.

Consequently, as a result of the different ethnicities, genders, and protocols used, the researchers proposed refer-

ence values to evaluate bone parameters (SOS, BUA, and BQI) for students living at a moderate altitude in Peru. The percentiles, in general, are widely used in medical practice for identifying individuals differing from the normal distribution of their population.<sup>22</sup>

The specific reference values proposed here may be used to assess bone health in different categories (normal, low quality, and very low bone quality). These are approximations for identifying subjects with greater risk in their skeletal status based on age and sex. These categories may be interpreted as normal (>p10), low quality (p3–p10), and at very low quality (<p3). These cut-off points are references, and they were based on a previous study with children and adolescents.<sup>23</sup> Therefore, they need to be analyzed with caution.

In essence, osteoporosis is a systemic bone disease that is characterized by low bone mass and a rapid deterioration of the micro-structures of the bone, resulting in bone fragility and eventual fractures.<sup>24</sup> In this context, QUS technology is a valuable tool to assess general bone resistance and strength quickly and accurately in student centers. Therefore, the proposed percentiles could assist in decision making at the student level (physical education classes) and in clinical settings (clinics, hospitals, and health centers).

The results of this research have shown that the bone parameters of children and adolescents from Arequipa

**Table 2** Percentiles for bone parameters [SOS (m/s), BUA (dB/MHz), and BQI ( $\alpha$ SOS +  $\beta$ BUA)] for children and adolescents from Arequipa (Peru).

Age (years)	Males									
	L	M	S	P3	P10	P25	P50	P75	P90	P97
	SOS									
6.0–6.9	−9.806	1520.3	0.012	1488.8	1498.0	1508.1	1520.3	1533.5	1546.7	1560.9
7.0–7.9	−12.545	1518.3	0.012	1488.4	1497.1	1506.6	1518.3	1531.3	1544.4	1559.0
8.0–8.9	−14.613	1515.1	0.012	1486.8	1494.9	1503.9	1515.1	1527.6	1540.5	1555.1
9.0–9.9	−15.061	1512.5	0.011	1485.4	1493.2	1501.8	1512.5	1524.4	1536.7	1550.5
10.0–10.9	−15.275	1510.7	0.011	1484.7	1492.2	1500.5	1510.7	1522.2	1533.9	1547.1
11.0–11.9	−17.291	1511.0	0.010	1485.7	1492.9	1501.0	1511.0	1522.3	1534.1	1547.6
12.0–12.9	−21.806	1514.0	0.011	1489.3	1496.2	1504.0	1514.0	1525.8	1538.4	1553.8
13.0–13.9	−28.380	1516.9	0.011	1492.6	1499.2	1506.8	1516.9	1529.4	1543.9	1563.8
14.0–14.9	−35.956	1518.3	0.011	1494.7	1500.9	1508.2	1518.3	1531.7	1549.2	1579.2
15.0–15.9	−43.649	1519.4	0.012	1496.5	1502.3	1509.3	1519.4	1533.8	1555.4	1620.6
16.0–16.9	−51.304	1535.6	0.012	1498.0	1503.4	1510.2	1520.3	1535.7	1564.2	1620.6
	BUA									
6.0–6.9	1.282	58.468	0.241	29.6	39.5	48.7	58.5	67.8	75.9	83.6
7.0–7.9	0.833	64.615	0.226	38.2	46.4	54.9	64.6	74.6	83.8	93.0
8.0–8.9	0.362	72.324	0.209	47.3	54.5	62.6	72.3	83.0	93.4	104.5
9.0–9.9	−0.010	78.260	0.189	54.9	61.4	68.9	78.3	88.9	99.7	111.7
10.0–10.9	−0.148	81.709	0.168	60.0	66.1	73.0	81.7	91.6	101.7	113.0
11.0–11.9	0.005	84.702	0.154	63.4	69.5	76.3	84.7	94.0	103.2	113.2
12.0–12.9	0.413	85.008	0.148	63.3	69.8	76.8	85.0	93.7	102.0	110.6
13.0–13.9	0.993	82.055	0.144	59.9	67.0	74.1	82.1	90.0	97.2	104.2
14.0–14.9	1.627	79.661	0.138	56.8	64.6	72.0	79.7	86.9	93.1	99.0
15.0–15.9	2.262	80.078	0.132	55.6	64.7	72.5	80.1	86.9	92.4	97.5
16.0–16.9	2.892	82.462	0.126	55.2	66.3	74.8	82.5	88.9	94.2	98.8
	BQI									
6.0–6.9	0.960	74.093	0.173	50.2	57.8	65.5	74.1	82.7	90.5	98.3
7.0–7.9	0.623	75.733	0.179	51.9	59.1	66.8	75.7	85.1	93.9	102.8
8.0–8.9	0.343	76.490	0.185	52.8	59.8	67.3	76.5	86.4	96.0	106.2
9.0–9.9	0.169	76.381	0.188	53.1	59.7	67.2	76.4	86.6	96.7	107.7
10.0–10.9	0.039	75.951	0.188	53.2	59.6	66.9	76.0	86.2	96.5	107.9
11.0–11.9	−0.141	77.535	0.189	54.8	61.1	68.3	77.5	88.2	99.3	111.7
12.0–12.9	−0.387	81.203	0.195	57.7	64.0	71.4	81.2	92.9	105.6	120.5
13.0–13.9	−0.689	83.800	0.203	59.7	66.0	73.5	83.8	96.7	111.5	130.3
14.0–14.9	−1.016	84.655	0.210	60.7	66.7	74.2	84.7	98.7	116.0	140.3
15.0–15.9	−1.361	85.064	0.216	61.5	67.2	74.5	85.1	100.1	120.5	153.8
16.0–16.9	−1.711	85.547	0.222	62.5	67.9	74.9	85.5	101.7	126.2	177.6

M, median; S, coefficient of variation; L, power in the Box-Cox transformation; SOS, speed of sound (m/s), at broadband ultrasound attenuation (BUA, dB/MHz), bone quality index (BQI =  $\alpha$ SOS +  $\beta$ BUA).

(Peru) are higher values of the SOS, and BQI when compared with the international reference.<sup>6</sup> However, with regard to the attenuation (BUA), until the onset of adolescence, both sexes of the students from Arequipa presented higher attention values than those of the international reference. However, for females in the last ages (15.0–16.9 years old), the attenuation values were similar to those of the reference. On the other hand, the males showed a drastic fall, but at advanced ages, they resembled the Hungarians. Perhaps, these patterns observed in the males are temporary changes produced by biological maturation since the fall seems to disappear at more advanced ages and close to adulthood.

The results from this current research could be related to a combination of factors that generally contribute to bone

strength of the students studied. Apparently, this observed phenomenon in children and adolescents living at a moderate altitude could be due to a greater width of the bones. These change slowly during the growth process. Consequently, in the long term, they are considered to be the determinants of bone strength throughout life.<sup>25</sup>

In fact, these physical characteristics observed in this study are related to ethnic factors since, according to Eveleth and Micozzi,<sup>26</sup> the mestizos from Peru, Bolivia, Guatemala, and Mexico, typically, are robust and short. In part, these factors could explain the results obtained in the present study. In spite of this, other factors could be at play, such as the impact of genetics, nutrition, and levels of physical activity.<sup>27</sup> However, in the past few years, 2001–2013, the Peruvian population has improved its caloric intake by

**Table 3** Percentiles for bone parameters [SOS (m/s), BUA (dB/MHz), and BQI ( $\alpha$ SOS +  $\beta$ BUA)] for children and adolescents from Arequipa (Peru).

Age (years)	Females									
	L	M	S	P3	P10	P25	P50	P75	P90	P97
SOS										
6.0–6.9	-20.382	1519.9	0.013	1489.9	1498.2	1507.7	1520.0	1534.8	1551.5	1572.8
7.0–7.9	-20.772	1514.3	0.013	1485.6	1493.5	1502.6	1514.3	1528.5	1544.2	1564.1
8.0–8.9	-19.647	1512.2	0.012	1484.1	1492.0	1500.9	1512.2	1525.7	1540.3	1558.2
9.0–9.9	-16.948	1512.6	0.012	1484.8	1492.7	1501.6	1512.6	1525.4	1538.8	1554.4
10.0–10.9	-15.029	1512.2	0.011	1484.9	1492.8	1501.5	1512.2	1524.3	1536.7	1550.8
11.0–11.9	-16.513	1513.7	0.011	1487.5	1495.0	1503.4	1513.7	1525.4	1537.6	1551.4
12.0–12.9	-20.993	1518.4	0.011	1493.2	1500.3	1508.3	1518.4	1530.3	1543.1	1558.6
13.0–13.9	-27.145	1523.5	0.011	1498.8	1505.5	1513.3	1523.5	1536.1	1550.7	1570.2
14.0–14.9	-33.712	1526.4	0.011	1502.0	1508.4	1516.0	1526.4	1540.1	1557.5	1585.7
15.0–15.9	-40.248	1526.1	0.012	1501.9	1508.0	1515.5	1526.1	1540.9	1562.6	1616.2
16.0–16.9	-46.674	1523.8	0.012	1499.9	1505.7	1513.0	1523.8	1540.01	1568.8	1616.2
BUA										
6.0–6.9	-0.376	65.871	0.190	47.1	52.2	58.1	65.9	75.1	85.0	96.6
7.0–7.9	-0.174	69.384	0.193	48.8	54.5	61.0	69.4	79.1	89.3	100.9
8.0–8.9	0.030	72.994	0.195	50.5	56.8	64.0	73.0	83.2	93.6	105.1
9.0–9.9	0.237	76.531	0.193	52.3	59.3	67.0	76.5	87.0	97.4	108.5
10.0–10.9	0.448	79.624	0.189	54.1	61.6	69.8	79.6	90.1	100.2	110.7
11.0–11.9	0.659	82.559	0.184	55.8	63.9	72.5	82.6	93.0	102.8	112.7
12.0–12.9	0.871	84.034	0.180	56.2	64.9	73.9	84.0	94.3	103.7	113.1
13.0–13.9	1.084	84.704	0.180	55.6	65.0	74.4	84.7	94.9	104.0	112.9
14.0–14.9	1.296	85.437	0.180	54.7	64.9	74.9	85.4	95.6	104.6	113.2
15.0–15.9	1.509	86.373	0.181	53.6	64.9	75.5	86.4	96.6	105.4	113.7
16.0–16.9	1.721	87.294	0.181	52.2	64.9	76.1	87.3	97.5	106.1	114.2
6.0–6.9	-0.257	76.885	0.224	51.5	58.3	66.3	76.9	89.7	103.7	120.2
BQI										
7.0–7.9	-0.441	73.115	0.213	50.6	56.5	63.6	73.1	84.8	97.8	113.5
8.0–8.9	-0.579	72.425	0.201	51.4	56.9	63.6	72.4	83.4	95.8	111.0
9.0–9.9	-0.636	74.702	0.188	54.3	59.7	66.1	74.7	85.3	97.1	111.5
10.0–10.9	-0.608	76.274	0.174	56.6	61.9	68.1	76.3	86.1	96.9	109.9
11.0–11.9	-0.568	78.723	0.163	59.3	64.6	70.7	78.7	88.2	98.4	110.3
12.0–12.9	-0.513	82.258	0.161	62.1	67.6	74.0	82.3	92.0	102.3	114.3
13.0–13.9	-0.444	85.849	0.167	64.0	70.0	76.9	85.8	96.4	107.5	120.4
14.0–14.9	-0.366	88.664	0.177	64.7	71.3	78.9	88.7	100.2	112.4	126.5
15.0–15.9	-0.283	89.589	0.190	63.8	70.8	79.0	89.6	102.0	115.2	130.4
16.0–16.9	-0.203	89.427	0.202	61.9	69.5	78.2	89.4	102.7	116.7	132.8

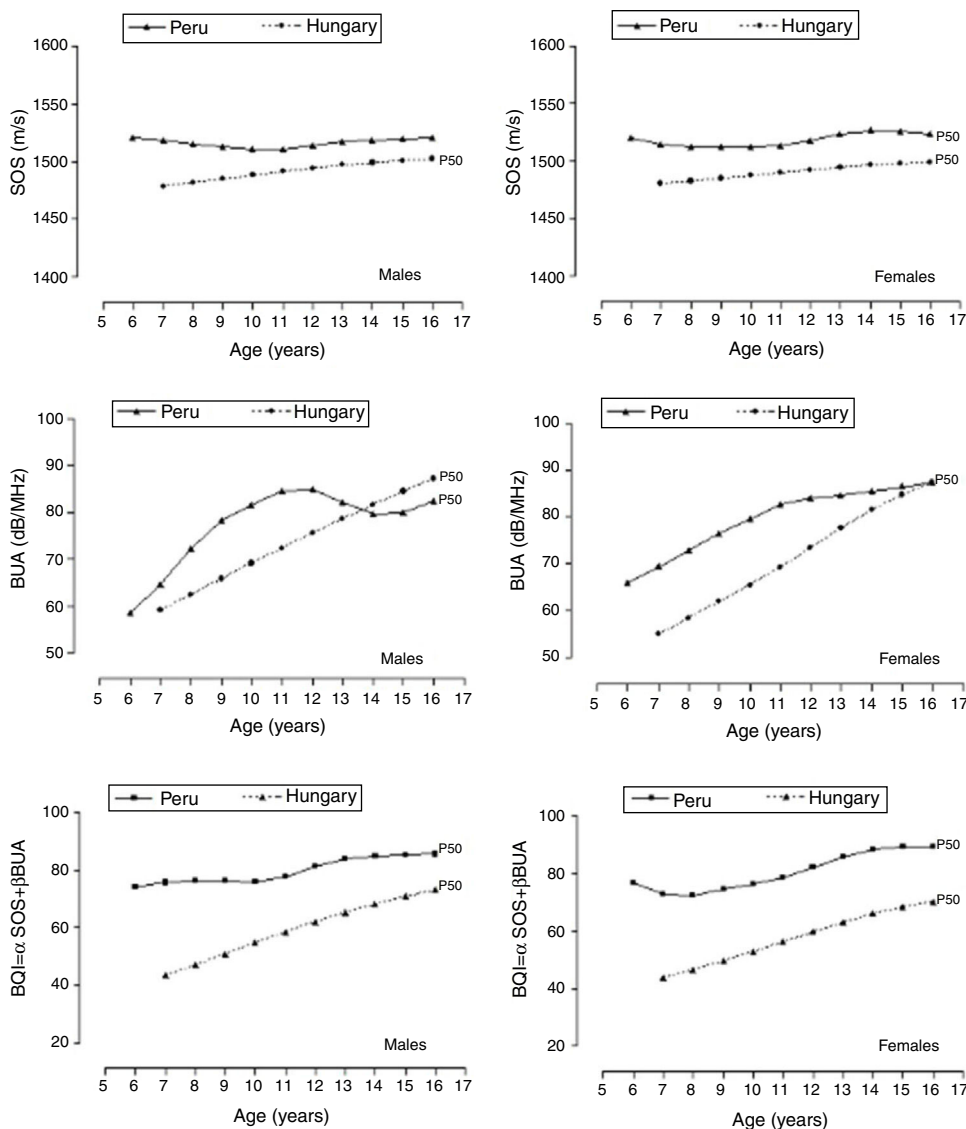
M, median; S, coefficient of variation; L, power in the Box-Cox transformation; SOS, speed of sound (m/s), at broadband ultrasound attenuation (BUA, dB/MHz), Bone quality index (BQI =  $\alpha$ SOS +  $\beta$ BUA).

14.8%.<sup>13</sup> In part, this may explain the relatively higher bone parameter values observed in this research.

In general, the increase in bone width is functionally driven by muscle growth.<sup>28</sup> These, in turn, are determined by nutrition with a high calcium intake (favors the periosteum) and the daily practice of physical activity.<sup>29</sup> The sum of these factors and ethnicity could account for the typical bone health characteristics of children and adolescents of diverse geographical regions around the world.

These parameters, in general, characterize modern societies independent of the altitude where individuals live and their lifestyle. Thus, it is well known that they change over time. Generally, these parameters reflect modifications in the bone structure and in bone mineral content as well as combinations of these.<sup>30</sup>

More studies are needed to verify the state of bone health of students living at a moderate altitude in Peru. Furthermore, conducting longitudinal studies could contribute to a more critical analysis of this type of population. In general, cross-sectional studies are limited to examining occurrences in a determined moment in time and place. In addition, it is necessary to control for the degree of physical activity, bone diameters, and the type of nutrition. These criteria could help characterize students living at a moderate altitude in Peru. However, on the contrary, this research study is the first one of its kind carried out in Peru. It could make a contribution as a reference study for researchers as well as for health care and sports professionals. The calculations for this research may be accessed online: [http://reidebihu.net/calcaneo\\_aqp.php](http://reidebihu.net/calcaneo_aqp.php).



**Figure 1** Graphic comparison (p50) of the bone parameters (QUS) of children and adolescents from Arequipa (Peru) and the Hungarian international reference. SOS, speed of sound; BUA, broadband ultrasound attenuation; BQI, bone quality index.

In conclusion, the students living at a moderate altitude in Peru presented slightly higher bone parameters when compared with the international reference. This pattern depicts a population with a better state of bone health. Furthermore, the proposed percentiles may be used with children and adolescents living at a moderate altitude in Peru. These percentiles may be used to identify, categorize, and monitor the degree of risk for bone disease based on age and sex.

**Conflict of interest**

The authors declare no conflicts of interest.

**Acknowledgments**

Santa Maria Catholic University Project, Arequipa, Peru.

**References**

1. Kaga M, Takahashi K, Suzuki H, Matsueda M, Moriwake T, Miyatake N. Ultrasound assessment of tibial cortical bone acquisition in Japanese children and adolescents. *J Bone Miner Metab.* 2002;20:111–5.
2. Zhu ZQ, Liu W, Xu CL, Han SM, Zu SY, Zhu GJ. Ultrasound bone densitometry of the calcaneus in healthy Chinese children and adolescents. *Osteoporos Int.* 2007;18:533–41.
3. Ch Kok-Yong, Ima-Nirwana S. Calcaneal quantitative ultrasound as a determinant of bone health status: what properties of bone does it reflect? *Int J Med Sci.* 2013;10:1778–83.
4. Guglielmi G, de Terlizzi F. Quantitative ultrasound in the assessment of osteoporosis. *Eur J Radiol.* 2009;71:425–31.
5. Weeks BK, Hirsch R, Nogueira RC, Beck BR. Is calcaneal broadband ultrasound attenuation a valid index of dualenergy x-ray absorptiometry-derived bone mass in children? *Bone Joint Res.* 2016;5:538–43.

6. Szmodis M, Zsakai A, Bosnyak E, Protzner A, Trajer E, Farkas A, et al. Reference data for ultrasound bone characteristics in Hungarian children aged 7–19 years. *Ann Human Biol.* 2017;44:704–14.
7. Madimenos FC, Snodgrass J, Blackwell AD, Liebert MA, Cepon TJ, Sugiyama LS. Normative calcaneal quantitative ultrasound data for the indigenous Shuar and non-Shuar Colonos of the Ecuadorian Amazon. *Arch Osteoporos.* 2011;6:39–49.
8. Sun HK, Woo K, Myung-Hee K. Effect of milk and milk products consumption on physical growth and bone mineral density in Korean adolescents. *Nutr Res Pract.* 2013;7:309–14.
9. Ramírez-Vélez R, Ojeda-Pardo M, Correa-Bautista J, González-Ruiz C, Navarro-Pérez C, González-Jiménez, et al. Normative data for calcaneal broadband ultrasound attenuation among children and adolescents from Colombia: the FUPRECOL Study. *Arch Osteoporos.* 2016;11:2.
10. Cossio-Bolaños MA, Santi-Maria T, Gomez-Campos R, Pascoal EH, Hespanhol JH, Arruda M. The use of World Health Organization growth curves in children and adolescents that live in regions of moderate altitude. *Revista Paulista de Pediatria.* 2012;30:314–20.
11. Díaz-Bonilla E, Torres-Galvis C, Gómez-Campos R, Arruda M, Pacheco-Carrillo J, Cossio-Bolaños MA. Weight, height and body mass index of children and adolescents of moderate altitude in Colombia. *Archivos Argentinos de Pediatría.* 2018;116:e241–50.
12. Cossio-Bolaños M, Arruda M, Andruske C, Luarte-Rocha C, Gómez-Campos R. Secular trends of physical growth and abdominal adiposity of school children and adolescents living at a moderate altitude in Peru. *Am J Phys Anthropol.* 2017;162:385–92.
13. Organización de las Naciones Unidas para la Alimentación y la Agricultura (FAO). Dirección de estadística de Balances Alimentarios; 2015 [cited 19 Apr 2019]. Available from: <http://faostat3.fao.org/home/S>
14. Cossio-Bolaños M, Gómez-Campos R, Andruske C, Viveros-Flores A, Luarte C, Olivares P, et al. Physical growth, biological age, and nutritional transitions of adolescents living at moderate altitudes in Peru. *Int J Environ Res Public Health.* 2015;12:12082–94.
15. Programa de las Naciones Unidas para el Desarrollo (PNUD). El ascenso del sur: Progreso humano en un mundo diverso. In: Informe sobre desarrollo humano. Programa de las Naciones Unidas para el Desarrollo 216, New York, EEUU. [cited 24 Apr 2019]. <http://www.undp.org/content/undp/en/home.html>.
16. Ross WD, Marfell-Jones MJ. Kinanthropometry. In: MacDougall JD, Wenger HA, Green HJ, editors. *Physiological testing of the high-performance athlete.* 2nd ed. Champaign, IL: Human Kinetics; 1991. p. 233–306.
17. Cole TJ, Green PJ. Smoothing reference centile curves: the LMS method and penalized likelihood. *Stat Med.* 1992;11:1305–19.
18. Pan H, Cole TJ [cited 28 March 2018]. Available from: <http://www.healthforallchildren.co.uk> LMS Chartmaker; 2006.
19. Prins SH, Jorgensen HL, Jorgensen LV, Hassager C. The role of quantitative ultrasound in the assessment of bone: a review. *Clin Physiol.* 1998;18:3–17.
20. Guglielmi G, Adams J, Link TM. Quantitative ultrasound in the assessment of skeletal status. *Eur Radiol.* 2009;19:1837–48.
21. Rivas-Ruiz R, Méndez-Sánchez L, Castelán-Martínez OD, Clark P, Tamayo J, Talavera JO, et al. Comparison of international reference values for bone speed of sound in pediatric populations: meta-analysis. *J Clin Densitom.* 2015;19:316–25.
22. van den Bergh JP, Noordam C, Ozyilmaz A, Hermus AR, Smals AG, Otten BJ. Calcaneal ultrasound imaging in healthy children and adolescents: relation of the ultrasound parameters BUA and SOS to age, body weight, height, foot dimensions and pubertal stage. *Osteoporos Int.* 2000;11:967–76.
23. Gomez-Campos R, Andruske CL, Md Arruda, Urta Albornoz C, Cossio-Bolaños M. Proposed equations and reference values for calculating bone health in children and adolescent based on age and sex. *PLoS ONE.* 2017;12:e0181918.
24. Doran PM, Khosla S. Osteoporosis. In: Hall JE, Nieman LK, editors. *Contemporary Endocrinology: Handbook of Diagnostic Endocrinology.* Totowa, NJ: Humana Press; 2003. p. 257–75.
25. Seeman E. Periosteal bone formation - a neglected determinant of bone strength. *N Engl J Med.* 2003;349:320–3.
26. Eveleth PB, Micozzi MS. Antropometría en el niño y enfermedades crónicas en el adulto. In: Cusminsky M, Moreno E, editors. *Crecimiento y desarrollo – hechos y tendencias.* Washington: Organization Panamericana de la Salud; 1988. p. 210–28.
27. Goh S, Aragon JM, Lee YS, Loke KY. Normative data for quantitative calcaneal ultrasound in Asian children. *Ann Acad Med Singapore.* 2011;40:74–9.
28. Rauch F. Bone growth in length and width: the yin and yang of bone stability. *J Musculoskelet Neuronal Interact.* 2005;5:194–201.
29. Parfitt AM. Parathyroid hormone and periosteal bone expansion. *J Bone Miner Res.* 2002;17:1741–3.
30. Ward K, Mughal Z, Adams J. Tools for measuring bone in children and adolescents. In: Sawyer AJ, Bachrach LK, Fung EB, editors. *Bone densitometry in growing patients. Guidelines for clinical practice.* Totowa, NJ: Humana Press; 2007. p. 15–40.