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Influence of Physical Fitness on the Quantitative Ultrasound Parameters at Calcaneus in Children

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ABSTRACT

The aim of this study was to investigate whether physical fitness influences the quantitative ultrasound (QUS) parameters in children. A total number of 693 school children, including of 343 boys and 350 girls, between 6-12 years of age were studied. Height, weight, foot length, and heel width were measured for an anthropometric analysis and the total score (fitness score) of the Japan fitness test, consisting of grip strength (kg), sit-up (times), sit and reach (cm), side step (points), 20 m shuttle run (times), standing long jump (cm), 50 m dash (sec), and ball throw (m), was used as an indicator for physical fitness. Broad-band ultrasound attenuation (BUA) and velocity of sound (VOS) at calcaneus were measured as the QUS parameters using CUBA Clinical Paediatric Research. The correlation coefficients and linear regression analyses revealed that a significant correlation existed between the QUS parameters and age, height, weight, foot length, heel width, and fitness score, respectively in both sexes except between heel width and VOS in girls. Multiple regression analyses were used to determine factors influencing the QUS parameters. In boys, the fitness score, weight, height, and heel width were independent predictors for BUA and fitness score, heel width, and height for VOS. In girls, weight, foot length, and fitness score were independent predictors for BUA and heel width, fitness score, weight, and foot length for VOS. In conclusion, physical fitness was found to have a significant influence on the QUS parameters in children. Ryukyu Med. J., 26(1,2)47-55, 2007

Key words: quantitative ultrasound method, broad-band ultrasound attenuation, velocity of sound, physical fitness, children

INTRODUCTION

Osteoporosis is a skeletal disorder characterized by compromised bone strength, thus predisposing patients to an increased risk of fracture. In Japan, osteoporosis affects over 10 million people and more than a hundred thousand people each year will suffer from femoral neck or trochanteric fractures as a result of osteoporosis. Following hip fracture, there is 10%-20% mortality within the first year, and 50% of the survivors will be unable to walk without assistance⁹. The majority of patients can not return to their pre-fracture lifestyle.

The prevention of osteoporosis is very important because it is difficult to cure osteoporosis once it has developed. There are two major strategies to prevent osteoporosis: one is gaining optimal peak bone mass which is achieved during childhood and adolescence, and the other is counteracting the process of age-related bone loss that occurs after menopause. Peak bone mass has been shown to be a good predictor of a risk for osteoporosis later in life because more than 85% of peak bone mass is acquired by the age of 18 years⁷. Therefore, maximizing bone mass during childhood and adolescence is crucial for the prevention of osteoporosis. Although much of peak bone mass is determined by genetic factors, environmental factors such as calcium intake and physical activity are also thought
Effects of physical fitness on the QUS parameters to be important. However, the results of studies investigating the effects of physical activity on bone mass remain controversial in children. Some studies showed no beneficial effect of physical activity, and a few others reported a positive relationship between physical activity and bone mineral density (BMD) in children. Further studies are needed to clarify the effects of physical activity on the bone mass in children.

Dual-energy X-ray absorptiometry (DXA) is currently the accepted indicator used to assess bone strength. However, DXA is not a standard tool in a primary care physician’s office because of expense, inconvenience, and reticence concerning X-ray exposure, particularly in children. Recently, quantitative ultrasound (QUS) method has been proposed as an alternative to DXA. The advantages of the QUS method are the simplicity in performing scans, a lack of ionizing radiation, and the relatively low expense. Moderate correlations have been reported between the BMD measured by DXA and the QUS parameters in children. In addition, QUS method could provide complementary information on skeletal properties such as the bone structure and elasticity.

The QUS parameters commonly used are broadband ultrasound attenuation (BUA) and velocity of sound (VOS). BUA is suggested to reflect the number and spatial orientation of cancellous bone trabeculae and bone density, and VOS is related to elastic properties of the bone and bone density, suggesting that not only bone density but also bone quality could be measured using the QUS method.

The purpose of this study is to determine whether the QUS parameters are influenced by physical fitness in children. Physical fitness indicates physical performance ability and includes cardio respiratory endurance, muscular strength, flexibility, and body composition. Physical fitness was measured by the Japanese new physical fitness test, instead of using self-reported physical activity, which is less objective especially for school children. In the present study, the factors which affected the QUS parameters were analyzed and showed that physical fitness could have a strong influence on the QUS parameters in children.

SUBJECTS and METHODS

Subjects

The study is a cross sectional survey with 693 healthy school children, including of 343 boys and 350 girls, aged from 6-12 years old. The participants were recruited from the local elementary school in the Okinawa, Japan. All parents were informed about the projects, and their consent was obtained. There were no children suffering from chronic diseases except for atopic dermatitis in three girls who were excluded from the study.

QUS measurements

The QUS measurements at the right calcaneus were performed using a CUBA Clinical™ Paediatric Research (McCue Ultrasonics Ltd., Winchester, UK). The QUS parameters measured with ultrasound were BUA and VOS. BUA (dB/MHz) is the attenuation of sound waves as they pass from the transmitting transducer to the receiving transducer (between two probes). VOS (m/sec) is the speed the ultrasound signal travels from one transducer to the other. The transducers have a diameter of 1.4 cm which was an ideal size for children. The same operator adjusted the foot position according to the size of individual feet to measure at a standard position, which is 1/2 of the way along the line, 45 degrees to the vertical, from the lateral malleolus to the most posterior part of the heel. Normal bone has a higher BUA and VOS than osteoporotic bone. Quality assurance was performed daily by calibrating the device on a dedicated phantom supplied by the manufacturer.

Anthropometric measurements

Height and body weight were measured using an electronic scale (Tanita Co., Tokyo, Japan). The length of the right foot was measured with a measuring board to the nearest 0.5 cm. The heel width was measured in millimeters automatically as the distance between transducers on the QUS device.

Assessment of physical fitness

Physical fitness was assessed by the Japanese new physical fitness test. This test is published by the Ministry of Education, Culture, Sports, Science and Technology (MEXT), which consists of eight test items: grip strength (kg), sit-ups
(upper body lifts, times), sit and reach (straight-leg forward bends, cm), side steps (points), 20-meter shuttle run (times), standing long jump (cm), 50-meter dash (sec), and softball throw (m). The details are described in the website http://www.mext.go.jp/a_menu/sports/stamina/03040901.htm. The results of the eight tests were converted into standardized scores that ranged from 1 to 10 according to the subjects’ grades and their sex. The total score adopted by the fitness score was used as an indicator for physical fitness. Higher scores represent a better performance. All tests were weighed equally.

Statistical analysis

The data are expressed as the mean ± SD. Differences between boys and girls were assessed by Student’s t-test. Analyses were performed separately for boys and girls. Pearson correlation coefficients and linear regression analyses were used to determine the associations among the variables. Then multiple stepwise regression analyses were performed with BUA and VOS as the dependent variables and the measurements correlated with the QUS parameters as independent variables. A P value >0.05 was used for variable removal. Values for R² refer to the adjusted coefficient of determination. In addition to the R² coefficient, multiple regression analyses provided β values to assess the absolute contribution for the prediction of the dependent variable by an independent variable. The statistical analysis was performed using the SPSS program for Windows, version 12 (SPSS, Inc., Troy, NY, USA). A P value < 0.05 was considered to be statistically significant.

RESULTS

The descriptive variables, the QUS parameters, and fitness scores for boys and girls are summarized in Table 1. Girls had a significantly higher BUA (P = 0.033) and VOS (P<0.001) than boys. BUA was linearly correlated with age (R² = 0.39, P<0.001 for boys, R² = 0.38, P=0.001 for girls), as shown in Figure 1. Correlations were also observed with height (R² = 0.54, P<0.001 for boys, R² = 0.49, P<0.001 for girls), weight (R² = 0.52, P<0.001 for boys, R² = 0.49, P=0.001 for girls) (Fig. 2), and fitness score (R² = 0.35, P<0.001 for boys, R² = 0.33, P<0.001 for girls) (Fig. 3). VOS was linearly but weakly correlated with age (R² = 0.11, P=0.001 for boys, R² = 0.04, P<0.001 for girls), as shown in Figure 1. Weak correlations were also seen with height (R² = 0.10, P<0.001 for boys, R² = 0.04, P<0.001 for girls), weight (R² = 0.02, P = 0.003 for boys, R² = 0.03, P = 0.002 for girls), and fitness score (R² = 0.19, P<0.001 for boys, R² = 0.07, P=0.001 for girls) (Fig. 3).

The correlation coefficients between the QUS parameters and other variables are presented in Table 2. BUA and VOS showed positive correlations with all other variables except between heel width and VOS in girls. Although heel width was not correlated with the VOS, it was found to be weakly associated with to VOS after adjustment for weight (data not shown). Correlations with BUA were substantially stronger than with VOS for all variables. Fitness score had a moderate correlation with the QUS parameters. Although the correlation between VOS and fitness score was not very strong, fitness score was the strongest predictor among all variables in both sexes.

Multiple stepwise regression analyses were performed to determine the significance of each variable correlated with one of the QUS parameters. The best multiple regression models explained 58.9% and 22.2% of the variation in BUA and VOS (Table 3). Fitness score (P<0.001), weight (P = 0.001), heel width (P = 0.022), and height (P = 0.042) were independent predictors for BUA in boys, and weight (P<0.001), foot length (P<0.001) and fitness score (P<0.04) were independent predictors for BUA in girls. On the other hand, fitness score (P<0.001), heel width (P<0.001), and height (P = 0.008) were independent predictors for VOS in boys, and heel width (P<0.001), fitness score (P<0.008), weight (P = 0.024), and foot length (P = 0.028) were independent predictors for VOS in girls. Fitness score was the most highly significant factor influencing both BUA and VOS in boys. In addition, fitness score explained more variability in VOS than BUA in both sexes.

DISCUSSION

The aim of this study was to investigate whether physical fitness influences the QUS parameters in children. These results clearly indicate that fitness score is a significant determinant of the QUS parameters, thus suggesting that
Table 1 Characteristics of study sample

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Boys (n=343)</th>
<th>Girls (n=350)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean ± SD</td>
<td>Range</td>
<td>Mean ± SD</td>
<td>Range</td>
</tr>
<tr>
<td>Age (year)</td>
<td>9.4 ± 1.8</td>
<td>6.3-12.8</td>
<td>9.5 ± 1.7</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>132.6 ± 11.7</td>
<td>109.8-165.0</td>
<td>133.5 ± 12.2</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>31.0 ± 10.2</td>
<td>14.7-87.5</td>
<td>30.6 ± 9.1</td>
</tr>
<tr>
<td>Foot length (cm)</td>
<td>21.1 ± 2.1</td>
<td>16.5-27.0</td>
<td>20.8 ± 1.9</td>
</tr>
<tr>
<td>Heel width (mm)</td>
<td>39 ± 5</td>
<td>28-55</td>
<td>38 ± 4</td>
</tr>
<tr>
<td>BUA (dB/MHz)</td>
<td>48.9 ± 13.5</td>
<td>6.5-100.3</td>
<td>51.2 ± 13.9</td>
</tr>
<tr>
<td>VOS (m/s)</td>
<td>1583 ± 25</td>
<td>1504-1665</td>
<td>1600 ± 29</td>
</tr>
</tbody>
</table>

Japan Fitness test

- Grip strength (kg): 14 ± 5 vs 13 ± 5, NS
- Sit-up (times): 16 ± 7 vs 14 ± 5, 0.002
- Sit & reach (cm): 31 ± 8 vs 34 ± 10, 0.001
- Side step (points): 35 ± 9 vs 33 ± 8, 0.017
- 50m run (sec): 10.6 ± 1.6 vs 10.6 ± 1.4, NS
- 20 m shuttle run (times): 28 ± 17 vs 22 ± 11, 0.001
- Ball throw (m): 18 ± 9 vs 9 ± 4, 0.001
- Standing long jump (cm): 131 ± 24 vs 123 ± 25, 0.001

Fitness score (points): 42 ± 13 vs 42 ± 12, NS

Values are the mean ± standard deviation (SD).
P value for continuous variables is obtained by Student's t-test between boys and girls.
BUA: broadband ultrasound attenuation, VOS: velocity of sound.

Fig. 1 The relationship between BUA and VOS and age in boys (left) and girls (right). Regression equation between BUA and age in boys: $Y = 3.20 + 4.85 \times X \quad (R^2 = 0.39, \ P<0.001)$. Regression equation in girls: $Y = 4.37 + 4.95 \times X \quad (R^2 = 0.38, \ P<0.001)$. Regression equation between VOS and age in boys: $Y = 1547.7 + 4.70 \times X \quad (R^2 = 0.011, \ P<0.001)$. Regression equation in girls: $Y = 1568.7 + 3.90 \times X \quad (R^2 = 0.04, \ P<0.001)$. 
Table 2  Pearson correlation coefficients (r) between QUS parameters and the other variants

<table>
<thead>
<tr>
<th>Variable</th>
<th>Boys</th>
<th></th>
<th></th>
<th></th>
<th>Girls</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r</td>
<td>P</td>
<td>r</td>
<td>P</td>
<td>r</td>
<td>P</td>
<td>r</td>
<td>P</td>
</tr>
<tr>
<td>Age (year)</td>
<td>0.628</td>
<td>&lt;0.001</td>
<td>0.384</td>
<td>&lt;0.001</td>
<td>0.619</td>
<td>&lt;0.001</td>
<td>0.197</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>0.732</td>
<td>&lt;0.001</td>
<td>0.290</td>
<td>&lt;0.001</td>
<td>0.698</td>
<td>&lt;0.001</td>
<td>0.214</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>0.720</td>
<td>&lt;0.001</td>
<td>0.162</td>
<td>&lt;0.001</td>
<td>0.721</td>
<td>&lt;0.001</td>
<td>0.168</td>
<td>0.002</td>
</tr>
<tr>
<td>Foot length (cm)</td>
<td>0.719</td>
<td>&lt;0.001</td>
<td>0.304</td>
<td>&lt;0.001</td>
<td>0.694</td>
<td>&lt;0.001</td>
<td>0.232</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Heel width (mm)</td>
<td>0.714</td>
<td>&lt;0.001</td>
<td>0.107</td>
<td>&lt;0.001</td>
<td>0.629</td>
<td>&lt;0.001</td>
<td>0.023</td>
<td>NS</td>
</tr>
<tr>
<td>Fitness score (points)</td>
<td>0.588</td>
<td>&lt;0.001</td>
<td>0.430</td>
<td>&lt;0.001</td>
<td>0.575</td>
<td>&lt;0.001</td>
<td>0.261</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Fig. 2 The relationship between BUA and height and weight in boys (left) and girls (right). Regression equation between BUA and height in boys: $Y = -63.60 + 0.85X$ ($R^2 = 0.54$, $P<0.001$). Regression equation in girls: $Y = -55.95 + 0.80X$ ($R^2 = 0.49$, $P<0.001$). Regression equation between BUA and weight in boys: $Y = 19.35 + 0.95X$ ($R^2 = 0.52$, $P<0.001$). Regression equation in girls: $Y = 17.62 + 1.11X$ ($R^2 = 0.49$, $P<0.001$).

physical fitness is an important factor for increasing peak bone mass and improving bone quality in children.

Based on the findings of previous studies, the candidates which affect the QUS parameters in children are genetic factors, age, weight, height, state of puberty, amount of calcium intake and physical activity. It is evident that lumbar BMD measured by DXA increases with age and peaks by the late twenties. Moderate correlations have been reported between BMD and the QUS parameters in children. In the current study, the QUS parameters increased with age, but the increases in VOS were smaller than BUA. Only a marginal VOS increase was observed with age. In addition, the anthropometric variables such as weight, height, foot length, and heel width, which are related to age, also correlated with BUA better than VOS. The same results were obtained by Wünsche et al. and Mughal et al. In contrast, Jaworski et al. reported a larger VOS increase with age, and Sundberg et al. reported an
Effects of physical fitness on the QUS parameters

Table 3  Multiple linear regression analysis to predict BUA and VOS

<table>
<thead>
<tr>
<th>Predictor</th>
<th>β ± SE</th>
<th>P</th>
<th>Predictor</th>
<th>β ± SE</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fitness score</td>
<td>0.290 ± 0.057</td>
<td>&lt; 0.001</td>
<td>Fitness score</td>
<td>0.435 ± 0.139</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Weight</td>
<td>0.299 ± 0.116</td>
<td>0.001</td>
<td>Heel width</td>
<td>-0.377 ± 0.482</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Heel width</td>
<td>0.188 ± 0.245</td>
<td>0.022</td>
<td>Height</td>
<td>0.283 ± 0.226</td>
<td>0.008</td>
</tr>
<tr>
<td>Boys Age</td>
<td>-0.004</td>
<td>NS</td>
<td>Boys Age</td>
<td>0.021</td>
<td>NS</td>
</tr>
<tr>
<td>Boys Foot length</td>
<td>0.133</td>
<td>NS</td>
<td>Boys Foot length</td>
<td>0.153</td>
<td>NS</td>
</tr>
<tr>
<td>Boys Weight</td>
<td>0.457 ± 0.086</td>
<td>&lt; 0.001</td>
<td>Boys Weight</td>
<td>0.201 ± 0.181</td>
<td>0.008</td>
</tr>
<tr>
<td>Boys Foot length</td>
<td>0.236 ± 0.531</td>
<td>0.001</td>
<td>Boys Foot length</td>
<td>0.228 ± 1.551</td>
<td>0.028</td>
</tr>
<tr>
<td>Boys Fitness score</td>
<td>0.110 ± 0.063</td>
<td>0.040</td>
<td>Boys Height</td>
<td>-0.134</td>
<td>NS</td>
</tr>
<tr>
<td>Girls Age</td>
<td>-0.035</td>
<td>NS</td>
<td>Girls Height</td>
<td>-0.007</td>
<td>NS</td>
</tr>
<tr>
<td>Girls Heel width</td>
<td>-0.019</td>
<td>NS</td>
<td>Girls Age</td>
<td>-0.035</td>
<td>NS</td>
</tr>
<tr>
<td>Girls Height</td>
<td>-0.007</td>
<td>NS</td>
<td>Girls Heel width</td>
<td>-0.019</td>
<td>NS</td>
</tr>
</tbody>
</table>

Adjusted R²: 0.589
Adjusted R²: 0.222

β: standardized partial regression coefficients, SE: standard error.
Adjusted R² values were all significant (P < 0.001).

Figure 3 The relationship between BUA and VOS and fitness score in boys (left) and girls (right). Regression equation between BUA and fitness score in boys: Y = 22.55 + 0.63 X (R² = 0.35, P < 0.001). Regression equation in girls: Y = 23.04 + 0.68 X (R² = 0.33, P < 0.001). Regression equation between VOS and fitness score in boys: Y = 1557.1 + 0.80 X (R² = 0.19, P < 0.001). Regression equation in girls: Y = 1573.1 + 0.60 X (R² = 0.07, P < 0.001).

Increase in VOS between 11 and 16 years, with r = 0.46 and 0.43 for boys and girls, respectively. These differences are possibly caused by using a different device to measure QUS parameters. Multiple regression analyses revealed that most of the growth related factors such as age, weight, and height, and foot length were confounding. Although fitness score was an independent predictor
for the QUS parameters in both sexes, the effect in boys was much stronger than in girls. Several studies have shown that body weight and Tanner stage were more important determinants of bone density than physical activity in girls. In the present study, the pubertal staging using the method of Tanner was not performed. The unknown pubertal status of the subjects remains a limitation of this study.

Several studies have found a significant relationship between physical activities and bone mass, or no association has been found between bone density and physical activity based on DXA measurements in adults. Although a positive correlation has been reported between high-impact weight-bearing activity and BMD in children measured by DXA, only a few reports are available on the relationship between physical activity and the QUS parameters in children. Lappe et al. reported a negative correlation between physical activity and VOS measured at the patella of prepubescent girls. On the contrary, Lehtonen-Veromaa et al. showed weak but significant correlation between physical activity and the QUS parameters, however, the children in this study included elite or sub elite athletes, gymnasts, or runners.

Although physical activity can be measured in many different ways, self-report questionnaires have been adopted to assess physical activity in many studies. These methods are subjective, relying on responses from the children. In the present study, physical fitness was measured by the Japanese new physical fitness test, instead of physical activity. No previous studies have reported on the relationship between physical fitness and the QUS parameters in school children.

It is important to understand the difference between physical fitness and physical activity. Although they are thought to be correlated, they are not the same. Physical activity is any body movement produced by the skeletal muscles, and the physical activity level is usually defined by frequency, duration, and intensity of physical activities. On the other hand, physical fitness is a person’s ability to perform physical activities that require agility, balance, cardiovascular endurance, flexibility, muscular strength and endurance, or speed, and is determined by a combination of regular activity and genetically inherited ability. Increased physical activity level is not necessarily associated with significantly better physical fitness performance. Physical fitness is probably a better outcome than self-reported physical activity in this type of study.

Bone quality is determined by the intrinsic material properties of the bone, trabecular architecture, microdamage accumulation, and accelerated remodeling. BUA reflects the spatial orientation of the bone trabeculae where the value increases with trabecular complexity. VOS, on the other hand, reflects the velocity of sound traveling through the bone and the surrounding soft tissue and it increases with the density of the structure. Therefore, it has been proposed that the QUS method could be a useful method for evaluating the strength and elasticity of bone. Previous studies have shown that the QUS parameters and BMD independently and effectively predicted osteoporotic fractures in women, thus suggesting that the QUS parameters reflect other properties of the bone besides bone mass in comparison to BMD.

In conclusion, the QUS method is thus considered to be a useful method to assess bone mass and bone quality in children. The application of QUS method to the assessment of bone is attractive, since the technique is radiation-free and the devices used are more portable and less expensive than the radiation-based equipment. Acquiring a high bone mass during childhood and adolescence is a key determinant of adult skeletal health. These results suggest that promoting physical fitness is one strategy for augmenting bone mass and improving bone quality in children.

REFERENCES

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