Original Article

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

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Abstract. We investigated the quantitative ultrasound (QUS) parameters broadband ultrasound attenuation (BUA) and speed of sound (SOS) measured in the posterior part of the calcaneus at the region of interest (ROI) with the lowest attenuation, using an ultrasound imaging device (UBIS 3000) in 491 healthy Caucasian children and adolescents (262 girls, 229 boys) between 6 and 21 years old. The relation of age, body weight, height, foot dimensions and pubertal stage to BUA and SOS was assessed. BUA increased nonlinearly with age in boys and girls, \( r^2 \) being 0.44 (\( p<0.001 \)) and 0.57 (\( p<0.001 \)), respectively. SOS increased linearly with age in girls (\( r = 0.04, p<0.001 \)). There was no significant increase in SOS in boys (\( r^2 = 0.01, p>0.05 \)). Heel width was significantly correlated with BUA (\( r = 0.20, p<0.005 \) in boys; \( r = 0.27, p<0.05 \) in girls) and with SOS (\( r = -0.19, p<0.005 \) in boys; \( r = -0.08, p<0.05 \) in girls). After downward adjustment of the ROI size according to foot length quartiles, significantly lower BUA and SOS values were found compared with those with the standard ROI size of 14 mm. After correction for heel width and adjustment of the ROI size based on foot length, BUA and SOS were significantly associated with age in boys (\( r^2 = 0.36, p<0.001 \) and 0.06, \( p<0.05 \)) and in girls (\( r^2 = 0.53 \) and 0.06, both \( p<0.001 \)). Tanner stage was significantly correlated with BUA (\( r = 0.62, p<0.001 \)) in boys; \( r = 0.73, p<0.001 \) in girls) but not with SOS. BUA but not SOS increased significantly with the number of years since menarche (\( p<0.001 \)). In a multiple stepwise regression analysis in boys, age, weight and foot length were independent predictors for BUA, and age and foot length for SOS. In girls, age and weight were independent predictors for BUA and age was the only independent predictor for SOS. After correction for age, pubertal stages and heel width were no longer determinants for QUS parameters in either boys or girls. In conclusion, BUA increased significantly with age in both sexes. SOS increased with age in both boys and girls, but the increase was small and not statistically significant in boys. SOS, as measured with the UBIS 3000 device, may therefore not be appropriate to assess skeletal status in healthy children. Whether SOS and BUA are affected in children with skeletal disorders has yet to be determined. In boys, age, weight and foot length were independent predictors for BUA and age and foot length for SOS. In girls, age and weight were independent predictors for BUA and age was the only independent predictor for SOS. In our opinion, children with small feet should be measured with a smaller ROI diameter than those with larger feet.

Keywords: Adolescents; BUA; Children; Puberty; SOS; Ultrasound

Introduction

There is a growing interest in the use of quantitative ultrasound (QUS) measurements as an alternative to radiation-based densitometry techniques for the non-invasive assessment of osteoporosis [1,2]. Since the late
1980s, a number of devices have been developed for QUS assessment at peripheral skeletal sites with little overlying soft tissue (e.g. phalanx, tibia or calcaneus). For measurements of the calcaneus broadband ultrasound attenuation (BUA) and velocity or speed of sound (SOS) are the two most commonly used QUS parameters [3].

Prospective studies have shown the value of calcaneal ultrasound measurements for the prediction of osteoporotic fractures in women [4,5], even after correction for bone mineral density (BMD) [6,7], which suggests that QUS reflects other properties of bone than density alone. In vitro, there is indeed evidence that QUS parameters are not only density- but also structure-related [8,9]. In vivo, there is a strong correlation between QUS parameters and BMD, when both are measured at the calcaneus [10,11]. However, correlations between QUS measurements at the calcaneus and BMD measurements at the spine or the femoral neck are only modest [12–14], which may be caused by the fact that different skeletal sites are compared.

In children, bone mass measurements are important for the assessment of adverse effects of (treatment of) disease on bone mass development and eventually peak bone mass. The application of QUS to the assessment of disorders of the developing skeleton is attractive, since the technique is radiation-free, and the devices used are more portable and less expensive than radiation-based equipment. At present, there are only a few published papers on QUS in children. Correlation coefficients between calcaneal QUS parameters on one hand and total body BMD, lumbar spine BMD, femoral neck BMD and heel BMD on the other have been reported to range from 0.44 to 0.83 in healthy children [15–17]. Furthermore, a relation between phalangeal or patellar SOS and age, height and body weight has been reported in boys and girls between 9 and 15 years and between 8 and 18 years old, respectively [18,19]. SOS [15,20] and BUA [15,16,21] measured at the calcaneus were also associated with age in boys and girls between 6 and 15 years.

To date, ultrasound parameters in children have been assessed with non imaging methods. With the calcaneal ultrasound imaging device used in the present study, it is possible to visualize the region of measurement, which may be helpful in children, since the size of the calcaneus increases with age. The influence of the size of the measured region on BUA and SOS has not been studied. Furthermore, there are no data in children concerning the influence of foot dimensions on BUA and SOS scores, and data on the relationship between pubertal stages and calcaneal BUA and SOS are limited.

The purpose of the present study was first to establish an age-dependent reference range for BUA and SOS at the calcaneus in children and adolescents between 6 and 21 years old using an imaging device and second to determine the influence of body weight, height, foot dimensions and pubertal stage on QUS parameters.

Subjects and Methods

Subject Selection and Mode of Recruitment

A total of 569 Caucasian children and adolescents between 6 and 21 years old were invited to participate in this study. From them, 535 children and adolescents (94%) entered the study and were examined (285 girls, 250 boys). The participants were recruited from 5 primary schools and 7 secondary schools in the area of Nijmegen, The Netherlands. The Ethical Committee of the University Hospital Nijmegen approved the study protocol. Written informed consent was obtained from parents or from the children themselves when older than 16 years of age. Children who were treated with anticonvulsants or corticosteroids, or who were suffering from metabolic bone disease, diseases of the liver, kidneys or thyroid, cystic fibrosis or diabetes mellitus, were excluded from the study (n = 21). One boy with a calcaneal fracture in the past was also excluded.

Anthropometric Parameters

Height was measured with a fixed stadiometer to the nearest millimeter. Weight was measured without shoes on a standard clinical balance. Heel width was measured in millimeters with a Vernier calliper, at the location 1 cm below the internal malleolus and 2.5 cm from the back of the heel. The length of the right foot was measured in centimeters, with a measuring tape in standing position. All measurements were performed twice; the mean result is reported. The coefficient of variation for heel width measurements was 0.30% and 0.34% and for foot length 0.07% and 0.08%, in boys and girls, respectively.

Pubertal status was determined with the Tanner scale and was evaluated by self-assessment of breast development and pubic hair growth in girls and of genital development and pubic hair growth in boys as reported previously [22]. Children were given pictures and written descriptions and were asked to select the picture that most accurately reflected their appearance. When there was a discrepancy between the two values, the degree of breast development in girls and genital development in boys was emphasized for the determination of the Tanner stage. The Tanner stages ranged from 1 to 5, with stage 1 being no pubertal development and stage 5 being the adult stage.

Ultrasound Measurements

QUS measurements were performed by two trained operators using the ultrasound bone imaging scanner UBIS 3000 (DMS, Montpellier, France). The calcaneus was scanned in two directions using a pair of 0.5 MHz focused broadband transducers with a diameter of 25 mm, immersed in a waterbath at a temperature of 30 °C. The acoustic properties broadband ultrasound attenuation