Comparison of Six Calcaneal Quantitative Ultrasound Devices: Precision and Hip Fracture Discrimination

Osteoporosis and Arthritis Research Group, Department of Radiology, University of California, San Francisco, USA

Abstract. Quantitative ultrasound (QUS) is now accepted as a useful tool in the management of osteoporosis. There are a variety of QUS devices clinically available with a number of differences among them, including their coupling methods, parameter calculation algorithms and sites of measurement. This study evaluated the abilities of six calcaneal QUS devices to discriminate between normal and hip-fractured subjects compared with the established method of dual-energy X-ray absorptiometry (DXA). The short-term and mid-term precisions of these devices were also determined. Thirty-five women (mean age 74.5 ± 7.9 years) who had sustained a hip fracture within the past 3 years, and 35 age-matched controls (75.8 ± 5.6 years) were recruited. Ultrasound measurements were acquired using six ultrasound devices: three gel-coupled and three water-coupled devices. Bone mineral density was measured at the hip using DXA. Discrimination of fracture patients versus controls was assessed using logistic regression analysis (expressed as age- and BMI-adjusted odds ratios per standard deviation decrease with 95% confidence interval) and receiver operating characteristic (ROC) curve analysis. Measurement precision was standardized to the biological range (sCV). The sCV ranged from 3.14% to 5.5% for speed of sound (SOS) and from 2.45% to 6.01% for broadband ultrasound attenuation (BUA). The standardized medium-term precision ranged from 4.33% to 8.43% for SOS and from 2.77% to 6.91% for BUA. The pairwise Pearson correlation coefficients between different devices were highly significant (SOS, \( r = 0.79–0.93 \); BUA, \( r = 0.71–0.92 \)). QUS variables correlated weakly, though significantly, with femoral BMD (SOS, \( r = 0.30–0.55 \); BUA, \( r = 0.35–0.61 \)). The absolute BUA and SOS values varied among devices. The gel-coupled devices generally had a higher SOS than water-coupled devices. Bone mineral density (BMD) and BUA were weakly correlated with weight (\( r = 0.48–0.57 \) for BMD and \( r = 0.18–0.54 \) for BUA), whereas SOS was independent of weight. All the QUS devices gave similar, statistically significant hip fracture discrimination for both SOS and BUA measures. The odds ratios for SOS (2.1–2.8) and BUA (2.4–3.4) were comparable to those for femoral BMD (2.6–3.5), as were the area under the curve (SOS, 0.65–0.71; BUA, 0.62–0.71; BMD, 0.65–0.74) from ROC analysis. Within the limitation of the sample size all devices show similar diagnostic sensitivity.

Keywords: Hip fracture; Osteoporosis; Precision; Ultrasound attenuation; Ultrasound velocity

Introduction

Osteoporosis is now recognized as a major worldwide public health problem, causing a considerable financial burden. While there are established techniques for the diagnosis of osteoporosis, such as dual-energy X-ray absorptiometry (DXA) and quantitative computed tomography (QCT) [1,2], there is still a need for improvement. The relevant clinical end-point of osteoporosis is fracture, and bone strength is an important determinant of fracture risk. It is evident from the literature that in vitro density is a good predictor of bone strength,
accounting for between 65% and 80% of its variance [3]. However, there is a general need to improve estimation of bone strength in vivo, and ultimately of fracture risk. Bone strength is dependent on other parameters such as the architecture and geometry of the sample [4]. It is possible that ultrasound might give some architectural information about the bone and thus improve strength estimation. There is a growing interest in potential applications of quantitative ultrasound (QUS), because it is non-ionizing, relatively portable and relatively less expensive than DXA [3,5,6].

Clinical QUS devices became available in the early 1990s. Most measure speed of sound (SOS) and/or broadband ultrasound attenuation (BUA) at the calcaneus. Though based on similar principles, QUS instruments from different manufacturers have significant differences, particularly in their calibration methods, sites of measurement (mainly calcaneus, phalanges or tibia), analysis software and scanner design [3,6]. These devices also vary in the mode of data acquisition (fixed single point or imaging), coupling (water or gel), velocity definition (bone velocity, time of flight, speed of sound) and transit time measurement [3,7,8]. These differences cause readings obtained on different instruments to vary significantly. As a consequence, results are not directly comparable between different QUS devices [9], and each system must be evaluated independently for its clinical utility and precision. In addition to equipment drift, precision is also affected by external factors. These factors include heel positioning, water temperature, soft tissue temperature, immersion time, edema and deteriorating transducer pads [10–13].

The ability of most of the clinically available QUS devices to discriminate between fractured and normal subjects has been reported [14,15]. Because of the differences in the devices it is difficult to assess whether all calcaneal QUS devices have similar discriminatory abilities, because cross-sectional odds ratios are affected by the population used. Similarly, measurement precision has been reported for most calcaneal QUS devices [3,16]. Precision expressed as a ratio of standard deviation and mean does not take into account the different biological ranges or responsiveness of the different systems. Hence for precision to be comparable it must be standardized. Several approaches have been suggested to standardize coefficient of variation (CV) for easy comparison of different systems, although no consensus has been reached [17–19]. Ideally comparative assessment of the QUS devices should be carried out on the same population. No such study has been reported apart from that of Greenspan et al. [20]. However, their study was limited to only four QUS devices: Achilles (Lunar, Madison, WI); CUBA (McCue Ultrasonics, Hampshire, UK) and UBA 575+ (formerly Walker Sonix, now Hologic) and a prototype QUS-1X, (Osteo Sciences, presently marketed by Metra).

This study evaluated six calcaneal QUS devices: three gel-coupled and three water-coupled devices. The evaluation included short- and mid-term precision, correlations between devices and an assessment of the ability to discriminate hip-fractured patients from normal subjects. DXA measurements at the femur were also used to provide comparative assessment in terms of discriminatory ability.

Materials and Methods

Subjects

Seventy postmenopausal Caucasian women aged 52–94 years (mean age ± SD: 75.2 ± 6.8 years) living in the San Francisco Bay Area were recruited for this study by newspaper advertisements. Of the 70 subjects, 35 women aged 74.5 ± 7.9 years were identified by history and medical records as having hip fractures within the last 3 years and were used as the fracture group. Mean time since the hip fracture was 21.8 ± 9.2 months. Subjects were included in the fracture group only if the fracture resulted from a fall from standing height or less and involved no motion greater than walking. The fracture patients participating in the study had recovered and were able to walk freely without walkers or help from others. For each 5-year interval of age distribution of the women with hip fractures, the same number of postmenopausal, Caucasian women without a fracture of the hip were recruited as the control group. Thirty-five control women aged 75.8 ± 5.6 years were recruited from the same community by advertisements in the same newspaper.

The following characteristics applied to both study groups. All the women had ceased menstruating at least 6 months prior to the investigation. Menopause was defined as the time after the last menstruation. For each subject, height and weight were recorded and body mass index (BMI = weight/height²) was calculated. The medical history of all participants was obtained with an enrollment questionnaire. Women with hormone replacement therapy for more than 6 months within the last 10 years, Paget’s disease of the bone, juvenile diabetes, renal failure, or malignant disease with metastatic tumor were excluded from this study. We also excluded women who had taken calcitonin, bisphosphonates, anabolic steroids, fluoride, or parathyroid hormone for more than 3 months within the last 3 years. All subjects reported a non-existence of vertebral fractures.

For medium-term precision, a total of 10 healthy young male and female volunteers with a mean age of 37 ± 5 years were recruited.

The University of California, San Francisco Committee on Human Research approved the study protocol. All study participants gave written informed consent after the study had been explained to them.

Ultrasound Devices and Measurements

Measurements were acquired using six calcaneal ultrasound devices: Achilles+ (Lunar, Madison, WI),