Evaluation Of The Bias On X-Ray Absorptiometry And Quantitative Ultrasound Measurements Due To Bone-Seeking Elements

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1 Introduction

Dual-energy x-ray absorptiometry (DXA) is the current clinical gold standard of bone mineral density (BMD) estimation for the diagnosis and monitoring of osteoporosis. DXA measures areal bone mineral density (aBMD) based on the difference in x-ray photon attenuation between bone and surrounding soft tissue. Substitution of calcium (Ca, Z = 20) with bone-seeking elements such as strontium (Sr, Z = 38), lead (Pb, Z = 82) and aluminum (Al, Z = 13) can change the overall photon attenuation of bone, and can result in inaccurate estimations of aBMD [1].

Quantitative ultrasound (QUS) is an alternative bone densitometry technique that estimates BMD based on broadband ultrasound attenuation (BUA) and speed of sound (SOS) measurements. A derived quantity termed the stiffness index (SI) is calculated from BUA and SOS, and it is converted to yield an estimated BMD [2].

The objective of this study was to use bone-mimicking phantoms that contain strontium, lead or aluminum to assess the effect of the bone-seeking elements on DXA and QUS measurements.

2 Method

2.1 Production of bone-mimicking phantoms

Hydroxyapatite (HA) phantoms that are equivalent to bone mineral were synthesized using the method developed by Da Silva *et al*. [3, 4]. Seven HA phantoms that contain varying molar percentages of strontium [Sr/(Sr+Ca)] ranging from 0 to 2% were produced. In case of lead and aluminum, five HA phantoms that contain varying concentrations of the elements ranging from 0 to 200 ppm were produced for each element.

To produce bone mimicking phantoms, finely powdered HA phantoms were mixed with 5% *w*/*w* porcine gelatin solution [5]. The mixtures of gelatin and HA were poured into a container with the dimension of 6.5 cm x 6.5 cm x 2.5 cm to yield constant volumetric BMD (vBMD) of 200 mg/cm^3.

2.2 DXA measurements

aBMD of the constructed bone-mimicking phantoms were assessed using Hologic Horizon® DXA. The phantoms were submerged in water to simulate soft tissue that surrounds bone. Each phantom was measured ten times and was repositioned between each measurement.

2.3 Clinical QUS measurements

BUA, SOS and SI of the bone-mimicking phantoms were measured using Hologic Sahara® QUS device. The phantoms were placed in an acrylic box with a thin Mylar window. The box was filled with castor oil to eliminate air gaps and to simulate soft tissue. Each phantom was measured five times and was repositioned between each measurement.

2.4 In-house research QUS measurements

Additional QUS measurements were obtained using an in-house research system. The in-house research QUS system consisted of two 1 MHz transducers that are placed 20 cm apart, and the transducers were submerged under de-gassed and deionized water. The trabecular bone-mimicking phantom housed in the acrylic box with the castor oil filler was placed in the middle of the two transducers for measurements. Each phantom was measured five times and was repositioned between each measurement.

3 Results

The measured parameters were plotted as a function of concentration of strontium, lead and aluminum in Figure 1, 2 and 3, respectively. As shown in Figure 1, a strong linear relationship was observed between aBMD and strontium concentration (r = 0.995, p < 0.001). However, no statistically significant relationship (p > 0.05) was observed between aBMD and lead or aluminum concentrations.

Furthermore, no statistically significant relationship was found between all parameters measured by clinical QUS and strontium or aluminum concentrations. In the case of clinical QUS, BUA was found to vary linearly with lead concentration, (r = 0.899, p < 0.038). However, no statistically significant changes were observed for SOS or SI.

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For the research QUS system, no statistically significant correlations were observed for all three parameters in relation to all the bone-seeking elements.

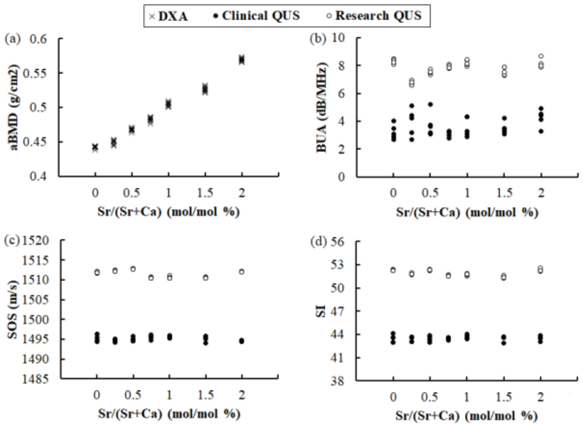

Figure 1: (a) aBMD measured by DXA, (b) BUA, (c) SOS and (d) SI measured by clinical and research QUS systems with respect to strontium concentration in mol/mol%.

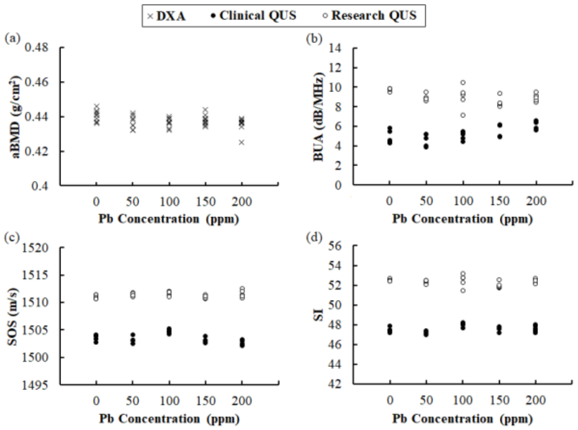

Figure 2: (a) aBMD measured by DXA, (b) BUA, (c) SOS and (d) SI measured by clinical and research QUS systems with respect to lead concentration in ppm.

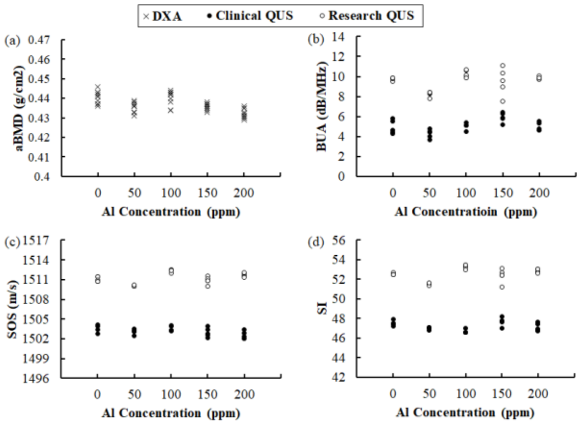

Figure 3: (a) aBMD measured by DXA, (b) BUA, (c) SOS and (d) SI measured by clinical and research QUS systems with respect to aluminum concentration in ppm.

4 Discussion

The observed strong linear relationship between aBMD and strontium concentration was consistent with previous studies [1]. In case of lead and aluminum, although a bias in aBMD was expected, the clinically relevant concentrations of the two elements were too low to induce significant deviation in the aBMD measurements.

Although there was a linear correlation between BUA and lead concentration, it should be noted that SI did not undergo statistically significant change under clinically relevant concentrations. This was observed for all three elements. Since SI is the basis for the BMD estimation of the QUS system, these results suggest that the estimation of BMD by QUS is not influenced by the clinically relevant concentrations of strontium, lead or aluminum.

5 Conclusion

This study demonstrates that strontium substitution of calcium can induce overestimation of aBMD, as previously reported, when measured by DXA. In contrast, QUS measurements were independent of the strontium concentration. In addition, clinically relevant levels of lead and aluminum do not seem to influence DXA and QUS measurements.

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