Measuring Composition of Bone Marrow by Partial Water and Fat Suppression Proton Projection MRI (WASPI) for Correction of X-Ray Measurement of Bone Mineral Density

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Introduction

Quantitative computed tomography (QCT) is a widely-used three-dimensional X-ray based method to measure bone mineral density (BMD). However, due to radiation concerns, QCT usually utilizes "single-energy" methods (SEQCT) and the variable adipose content of the marrow leads to errors caused by the differences between the linear attenuation coefficients of red and yellow marrow and from the overall volumetric density of the marrow (1). Estimates of the accuracy-error of QCT measurements in various body sites range from 2% to 30% (2). In addition to providing bone matrix density, water and fat suppressed proton projection MRI (WASPI) and partial-WASPI should be able to provide the needed information on marrow composition and content at the QCT scan site, which would correct the soft tissue contamination of the BMD measurement by QCT.

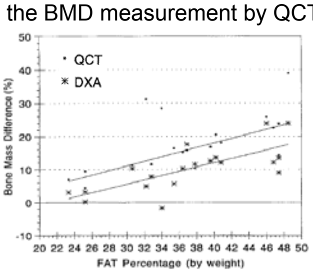

Figure 1.
Bone mass differences between normal and defatted bone as a percentage of the baseline measurement for QCT and DXA measurements versus fat percentage of the femoral neck determined by chemical analysis (from 2).

Methods

Partial WASPI only suppresses water or fat. If only the fat suppression pulse is applied, the MR intensity at the medullary cavity of the partial WASPI image represents the marrow water content; likewise, the MR intensity at the medullary cavity of the water-suppressed image indicates only the marrow fat content. The ratio of these two measurements should provide the water/fat ratio of the bone marrow.

The experiment was performed on a porcine tibia with a Siemens Trio 3T scanner. The WASPI protocol utilized in this study employed an excitation pulse of 10 μs (15°); receiver dead time 10 μs; dwell time 5μs; 120 mm FOV; 8148 projections (51 independent pixels in each dimension); and total imaging time of 17 min. Under this protocol, the projection voxel size was 2.4 mm in all three dimensions.

The image intensities of water and fat were corrected for T_1 saturation effects using a correction factor F:

$$F = \{1-\exp(-TR/T_1)\}(\sin\beta)/\{1-(\cos\beta)\exp(-TR/T_1)\}$$

where the T_1s of the water and marrow fat were 895 ms and 251 ms respectively from our previous studies, TR was 65 ms, and β was 15°.

References

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Acknowledgement

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Partial WASPI Measurement

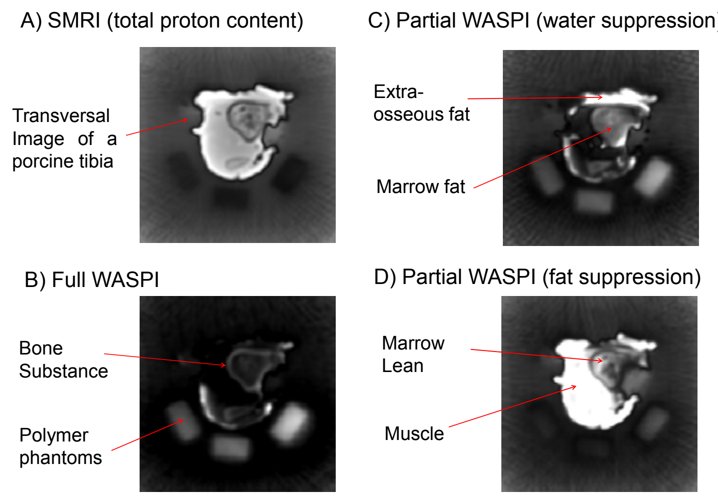

Figure 2.
Full WASPI and partial-WASPI images of a young porcine tibia specimen. A) Solid state MRI (SMRI) without suppression (total proton content). SMRI captures all the proton signals including liquid-state proton signal (water and fat) from bone marrow and muscle and solid-state proton signal from organic bone matrix. The polymer pellets can't be visualized since the liquid-state proton signal dominates the image. B) Full WASPI image. Both water and fat signals were suppressed and only solid state signals from bone matrix can be visualized. All three polymer pellets were observed clearly, which explains how WASPI visualizes the solid state signals. C) Partial WASPI with water suppression. Only fat signals can be visualized. D) Partial WASPI with fat suppression. Only water signals can be visualized.

The water/fat ratio in the medullary cavity of the proximal tibia was found to be 0.98 using partial WASPI. To verify this result, the marrow was taken out of the bone specimen after MRI and put into a glass tube for a spectroscopy study. Single pulse quantitative proton spectroscopy of the marrow with TR of 5 sec (5 X T1 of water) showed that the water/fat content was 0.93, which is very close to that obtained by partial WASPI.

Discussion and Conclusions

It is established in the literature that if the fat/water ratio in marrow is higher than that assumed in the QCT calibration procedure, the calculated BMD will be lower than the true BMD. On the other hand, if this ratio is lower than the QCT calibration assumption, the BMD value will be overestimated (3). In this preliminary study, we demonstrated that this ratio can be obtained accurately by partial WASPI. Calibration information for QCT bone mineral density measurement can be obtained as a function of bone marrow composition by partial WASPI on bone specimens of different ages and can be used for future measurements of bone mineral density in human subjects.