

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 for measurement of bone mineral density (BMD). However, due to radiation concerns, QCT usually utilizes “single-energy” methods and the variable adipose content of the marrow leads to errors which result from the differences between the linear attenuation coefficients of red and yellow marrow and from the overall volumetric density of the marrow (1). 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 so that the soft tissue contamination of the BMD measurement by QCT can be corrected.

Methods

For full (standard) WASPI imaging, both water and fat signals are suppressed and only the solid bone matrix signal survives. 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. Note that the water and fat content data are taken from matrix-free locations in the bone, so that matrix content does not contaminate the measurements. The measurement is less susceptible to errors than are other techniques such as two- or three-point Dixon or other spectroscopic sequences, and has the specific clear advantage for this study that the water and fat image data have intrinsically isotropic spatial resolution and map directly onto the MR matrix density images. Because high gradient strength is used in WASPI to image solid matrix, chemical shift artifacts are small.

Results

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 μ s (15°); receiver dead time 10 μ s; dwell time 5 μ s; 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, and the intrinsic resolution voxel size was even smaller since the resonance line width of solid bone matrix signal is about 2 kHz. Either the water or fat suppression pulse was applied for partial-WASPI. The image intensity at the medullary cavity was divided by a factor F to correct T₁ saturation effects:

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

where the T₁s of the water and fat of marrow were 895 ms and 251 ms respectively from our previous studies, TR was 65 ms, and β was 15°.

The water/fat ratio in the medullary cavity of the proximal tibia, where the signal in full WASPI was suppressed down to the baseline level, was found to be 0.98.

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

It has been 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 (2). 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.

References

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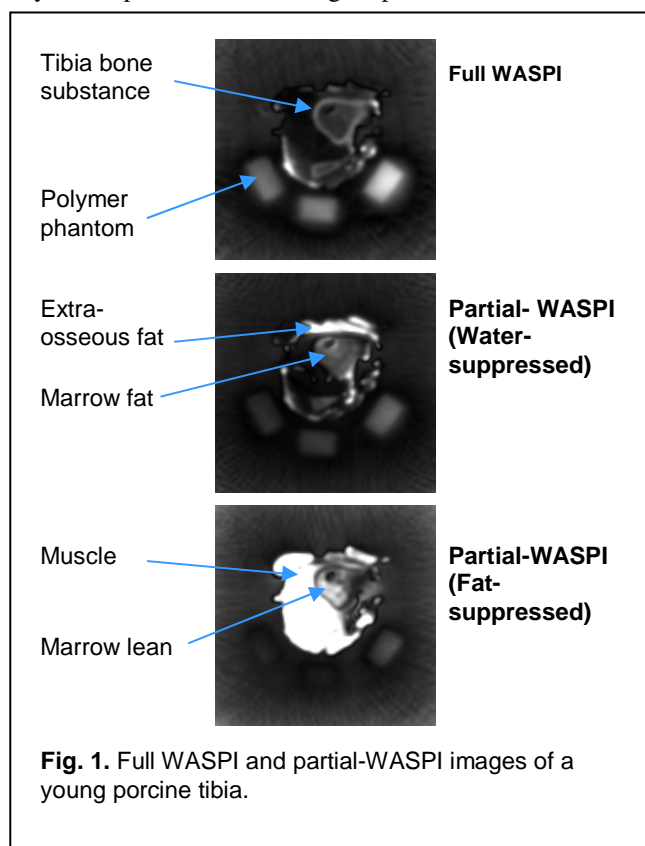


Fig. 1. Full WASPI and partial-WASPI images of a young porcine tibia.