A new method to predict structural parameters of trabecular bone at a standardized SNR level in high-resolution MRI studies of distal tibia

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Introduction

Structural parameters of trabecular bone quality—BV/TV, surface-to-curve-ratio, etc., computed at peripheral sites on the basis of high-resolution MR (μMR) images are known to be sensitive to signal-to-noise ratio (SNR). In time series μMR studies to investigate temporal changes in bone's micro-structure, images acquired at different time points can have variations in SNR as a result of involuntary subject motion, RF coil positioning, and body size which make estimation of temporal response in structural parameters unreliable. The purpose of this study is to investigate the feasibility of estimating structural parameter values at a standardized SNR value even when acquired images in a time series μMR study have different SNR values. Towards this goal, we created a mathematical model for SNR variations, trained it using ex-vivo and in-vivo images of distal tibia, and applied it to correct the BV/TV computed on the basis of μMR images acquired from an ongoing translational study to investigate the effect of renal transplantation on trabecular bone.

Methods

Image acquisition: The tibial metaphysis of 18 subjects (10 female and 8 male, 20-61 yr of age) were imaged using μMRI with a custom-designed receive coil and 3D FLASE pulse sequence [2] on a 1.5-T (Siemens Sonata) scanner at $137 \times 137 \times 410$-$\mu m^3$ voxel size with the third dimension being along the axial direction as part of a study to evaluate the effect of renal transplantation on bone's micro structure. Images of these subjects were used in the training phase of the mathematical model described below. In addition, another subject (32 yr) who produced an μMR image with poor SNR value (SNR=7.7) due to a defect in imaging hardware during the first attempt of the scan and who had to be rescanned within a week was used in the testing phase of the model.

Image processing: The k-space data were superimposed with Gaussian noise to yield a series of images with a range of SNR values (1-20) for each subject after Fourier transformed reconstruction. The SNR was defined as *s/n*, with *s* being the mean signal intensity of the trabecular bone region and *n* being the standard deviation of the noise added. Subsequently, resulting images were corrected for involuntary subject motion [3, 4] during the scan and image intensity variations across the volume produced by inhomogeneous sensitivity of the MR receiver coil were corrected using a local thresholding algorithm [5]. Bone-volume fraction (BV/TV) of the trabecular bone compartment was computed by Virtual Bone Biopsy (VBB) processing.

Generation and training of the model: Here, we created a linear model to relate the BV/TV value computed from an image at one SNR value (say SNR=α) to that computed from the same image at another SNR values (say SNR=β) after the addition of Gausian noise (This model was motivated by observations on SNR trends in cadaveric μMR images of distal tibia based on preliminary work). The linear model relating BV/TV computed at SNR values α and β can be expressed as BV/TV (SNR=β) = $a_{\alpha\beta}$ × BV/TV (SNR=α) + $b_{\alpha\beta}$ where $a_{\alpha\beta}$ and $b_{\alpha\beta}$ are two constants associated with the two SNR values used. The values of $a_{\alpha\beta}$ and $b_{\alpha\beta}$ were determined by a linear fitting of BV/TV values computed from the 18 datasets at the two SNR values α and β.

Predicted-model evaluation: Using the above model, an adjusted value of BV/TV can be computed at a standardized SNR value (say β) by taking the original BV/TV of an acquired image and its SNR (say α) as inputs. To evaluate the effectiveness of this model, the two μMR images of the repeat scan described above were used. The adjusted BV/TV values of the two images were computed at the higher SNR value of the two.

Results

Fig.1 (a) shows the variation in BV/TV when Gaussian noise was added on a μMR image. Fig.1 (b) shows one example of the linear relationship between BV/TV computed at two different SNR values (here, α=6 and β=12) for the 18 images. Fig.1 (c) shows the comparison between the adjusted BV/TV at SNR=β based on the relationship in (b) and the original BV/TV at SNR=β. Fig. 2 shows the two repeat μMR images used for testing the model. Table1 illustrates the BV/TV values of the two repeat images before and after model correction showing reduction of difference in BV/TV values of the two repeat images to 0.74% after correction compared to 4.85% before correction.

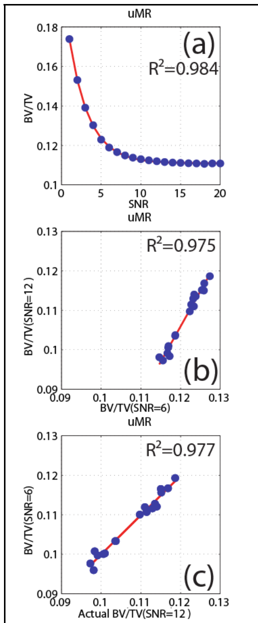
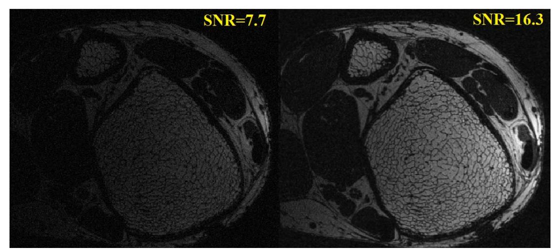


Figure 1. (a): BV/TV was plotted versus SNR; (b): BV/TV at SNR=6 was fit as a linear function of BV/TV at SNR=12; (c): the comparison of the adjusted and the original BV/TV at SNR=12.



(a) (b)

Figure 2. Two μMR images of the distal tibia scan: (a) baseline with much noise and SNR=7.7; (b) Three days follow up with SNR=16.3.

	Baseline	Follow up	Error (%)
SNR_original	7.7	16.3	52.80
SNR_adjusted	16.3	16.3	0.00
BV/TV_original	0.1216	0.1160	-4.85
BV/TV_adjusted	0.1168	0.1159	-0.74

Table1. The difference between baseline and follow up parameters before and after model correction. SNR_original and BV/TV_original were directly measured from the μMR images and as the inputs of the correction model. SNR_adjusted was set at the higher SNR the same as follow up. BV/TV_adjusted was the result derived from the correction model.

Conclusions

This correction model shows the BV/TV values can be effectively adjusted to a desired SNR value when facilitating longitudinal comparisons.

References

[1] Li, Med Phys, 2008; [2] Magland, MRI, 2009; [3] Song, MRM, 1999; [4] Lin, JMRI, 2007; [5] Vasilic, TMI, 2005; [6] Rajapakse, MRM, 2008; [7] Magland, MRI, 2009.

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