Investigation of Relationship between Free-Water T1 and Age in Human Cortical Bone Employing Short-TE 1H-MRI at 1.5T

Atena Akbari[1,2], Shahrokh Abbasi Rad[1,2], Mohsen Shojaee Moghaddam[3], and Hamidreza Saligheh Rad[1,2]

[1]*Medical Physics and Biomedical Engineering Department, Tehran University of Medical Sciences, Tehran, Tehran, Iran,* [2]*Quantitative MR Imaging and Spectroscopy Group, Research Center for Molecular and Cellular Imaging, Tehran, Tehran, Iran,* [3]*Imaging Center, Payambaran Hospital, Tehran, Tehran, Iran*

Target Audience

Researchers, scientists, clinicians and students who work in the field of quantifying cortical bone using MRI techniques

Purpose

Less than thirty percent of human cortical bone volume is composed of water which plays a pivotal role in its mechanical competence, from which only twenty percent appears as free water, occupying larger pores such as Haversian and Lacuno-canalicular systems **[1]**. The volume of cortical pores increases by aging and some bone related diseases such as Osteoporosis, leading to increase free water content; therefore, quantification of free water is a reliable measure to assess cortical bone porosity. Commercially available short-TE (STE) pulse sequences in clinics with the echo-time (TE) in the range of 0.5-1*m*sec are shown to be appropriate candidates to acquire enough signal from protons residing in large pores of human cortical bone, leading to successful quantification of free water T_1 values **[2]**. In the present work, we investigated relationship between STE-based cortical bone T_1 values and age, studies on a group of healthy volunteers at 1.5 T.

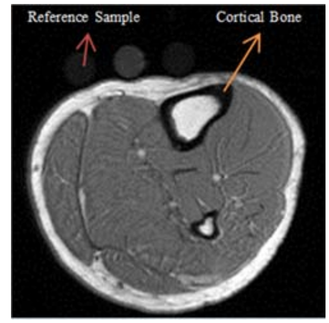

Fig. 1 A sample image of the mid-tibia acquired by the STE pulse sequence

Materials and Methods

Subjects: Eight normal volunteers, 3 males and 5 females (20-57yrs with the mean age of 37.4yrs), were incorporated into this study.

Image Acquisition: Mid-tibia images were acquired using STE pulse sequence with two different *TR* values on a 1.5T MR scanner (Siemens, Magnetom Avanto 18 channel) to implement previously proposed dual-*TR* technique for cortical bone T_1 quantification *in-vivo* **[2, 3].** The imaging parameters are selected to be: $TR_1/TR_2/TE$ = 20/60/1.19*m*sec, field-of-view (FOV) = 267×267*m*m^2, spatial resolution = 0.8×0.8*m*m^2, slice thickness = 5*m*m, flip angle = 20°, total scan time of about 20 minutes, using an 8-channel Tx/Rx knee coil (an example is shown in **Fig. 1**).

T_1-Quantification: Steps of quantification are as follows: (1) manual segmentation of the whole cortical bone at each of the two images with different *TR*s; (2) computation of the ratio value (r), as in **Eq. 1**, by dividing the mean signal intensities of the segmented cortical bone acquired from long-*TR* (TR_2) and short-*TR* (TR_1) images, respectively; (3) calculation of cortical bone T_1-value at each imaging slice by solving **Eq. 1** using nonlinear solver in MATLAB 7.14 (The MathWorks) **[2]**;

$$r = \frac{1-\exp(-\mathrm{TR}_1/\mathrm{T}_1)}{1-\mathrm{f_z}\exp(-\mathrm{TR}_1/\mathrm{T}_1)} \Big/ \frac{1-\exp(-\mathrm{TR}_2/\mathrm{T}_1)}{1-\mathrm{f_z}\exp(-\mathrm{TR}_2/\mathrm{T}_1)} \qquad \textbf{Eq. 1}$$

and (4) calculation of the average T_1-values for each subject and from ten different slices. As quantification of T_1-values are very sensitive to f_z – a parameter which characterizes the longitudinal magnetization as a function of pulse duration to the tissue T^*_2 (τ /T^*_2) **[4]** – it must be carefully determined based on Bloch equation simulation employing T^*_2 value of the cortical bone extracted from the literature at 1.5T, and parameters of the actual excitation pulse such as pulse shape and flip angle.

Evaluation of signal-to-noise ratio (SNR): SNR values, computed by dividing the mean signal intensities from segmented cortical bone in high-SNR (long-*TR*) images to the mean signal intensities from a region-of-interest (ROI) placed in the background noise, were in acceptable range for all slices (SNR>12). Steps to quantify T_1 and SNR values were shown in **Fig. 3**.

Table 1. Quantitative measurement of T_1 and SNR in 8 normal subjects

Subject	Age	Gender	T_1	SNR
1	20	F	120.95	14.12
2	28	F	162.92	13.60
3	29	F	183.47	14.10
4	34	F	220.37	17.52
5	38	M	233.46	18.25
6	46	M	204.65	13.44
7	47	F	206.20	12.95
8	57	M	290.50	15.83

Results

Table 1 shows results for quantitative measurement of T_1-values in eight healthy volunteers using STE pulse sequence. Measurements were performed for both genders, resulting in the mean T_1-values of about 202.81*m*sec for human cortical pore (free) water at 1.5T. Such T_1 quantity has been reported in the range of 380-775*m*sec and 200-400*m*sec at 4.7T **[5]** and 3T, respectively, showing rationale results achieved with the STE pulse sequence at 1.5T. T_1-values are strongly correlated with age as shown in **Fig. 2** (R^2=0.75, p<0.0001).

Discussions and Conclusions

Results suggest successful application of STE-MRI for accurate quantification of cortical bone T_1-values, with the advantages of total scan-time of about half of ultra-short TE's (UTE) pulse sequences, widespread clinical availability and cost-effective procedure, meaning that STE sequences can be utilized as proper alternatives in quantifying cortical bone parameters *in-vivo* **[2]**. Also this suggests that quantification of pore (free) water T_1 using STE is a reliable measure of cortical bone deterioration with age. Furthermore, our results follow the well-known theory describing cortical bone relaxivity as a function of its geometrical characteristics, $1/T_1 \propto (S/V)$ in which S and V are surface area and volume of the pore, respectively, meaning as surface-to-volume ratio decreases for larger cortical porosities due to aging, we see consistent increase in the T_1-values (R^2=0.75, p<0.0001) **[3]**.

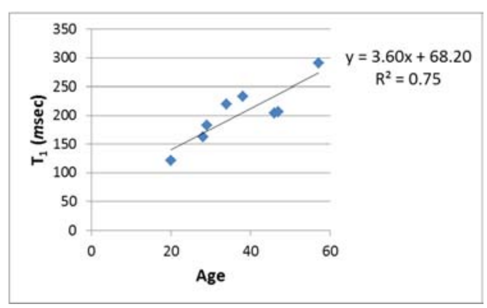

Fig. 2 Correlation between T_1 and Age in 8 healthy volunteers using STE pulse sequence (p<0.0001)

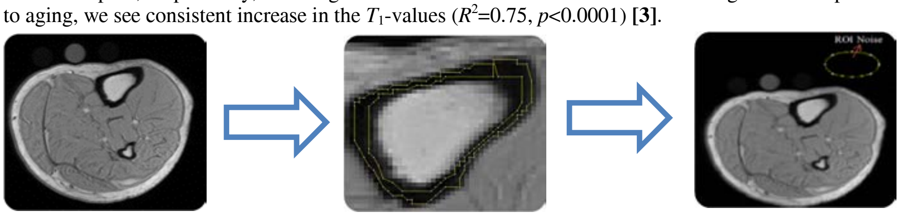

Image acquisition by STE pulse sequence | Cortical bone segmentation to obtain signal intensity | Placing ROI in the background noise to compute SNR

Fig. 3 Steps to acquire signal intensities from manually segmented cortical bone and background noise for T_1/SNR quantification purposes.

References: **[1]** Du J. *ISMRM 21* (2013) **[2]** Akbari A. *et al*, *ESMRMB 30* (2013) **[3]** Saligheh Rad H. *et al*, *NMR Biomed*, 23: 1-11 (2011) **[4]** Sussman M. *et al*, *MRM*, 40:890-899 (1998) **[5]** Horch RA. *Thesis* (2011)

Acknowledgement: MR Imaging and Spectroscopy were done at imaging center, Payambaran Hospital, Tehran, Iran.