Fat to Water Ratio and T2 Value Variations Measured in Lumbar, Thoracic, and Cervical Spinal Bone Marrow at 3 T

Quinn M. Barber[1] and Atiyah Yahya[1,2]

[1]*Department of Oncology, University of Alberta, Edmonton, Alberta, Canada,* [2]*Department of Medical Physics, Cross Cancer Institute, Edmonton, Alberta, Canada*

Target Audience: Researchers and clinicians interested in spinal bone marrow.

Purpose: To determine variations in fat to water ratios and fat and water T_2 (transverse relaxation) values in different vertebral regions of healthy volunteers with proton magnetic resonance spectroscopy (MRS) at 3 T. Fat to water ratios and their T_2 measures in spinal bone marrow have been shown to be relevant in the study of a number of diseases including osteoporosis and leukaemia. To understand changes in disease conditions it is important to have knowledge of fat to water ratios and their T_2 values in healthy vertebrae. Some previous studies have characterized fat and water in healthy vertebrae (1-4); however, *the measurements were limited to the lumbar region of the spine*. To our knowledge, a systematic study quantifying fat to water ratio changes going from the lumbar to the thoracic and to the cervical region has not been conducted before. In this work, we use proton MRS at 3 T to determine fat to water ratios and fat and water T_2 values in the lumbar, thoracic and cervical vertebral regions of healthy volunteers and characterize the variations in each volunteer.

Methods: Measurements were performed with a 3 T Philips Healthcare Intera whole body MRI scanner. The scanner's body coil was used for RF (radiofrequency) transmission and a Philips SENSE Head Spine coil was used for reception. Twenty healthy volunteers (8 female, 12 male) within the age range of 21 - 50 years were scanned. Spectra were acquired from each volunteer from the L3, T7 and C4 vertebrae using a Point RESolved Spectroscopy (PRESS) sequence (C4 data from one of the volunteers was not acquired due to time constraints). To estimate T_2 values, two spectra were obtained from each vertebra, one with a TE (echo time) of 40 ms and the other with a TE of 70 ms. Spectra were measured as 2048 complex data points sampled at a frequency of 2000 Hz in 32 averages (repetition time = 2.5 s). The RF pulse frequency offset was set to 3 ppm, centred between the water and methylene lipid resonances. PRESS voxel sizes were $(20 \times 20 \times 15)$ mm^3 for L3 vertebrae, $(15 \times 15 \times 12)$ mm^3 for T7 vertebrae, and $(9 \times 9 \times 9$ or $8 \times 8 \times 8)$ mm^3 for C4 vertebrae. Spectra were manually processed using Philips spectroscopy processing software and peaks were then fitted using a Philips automated spectral fitting software. The software yielded peak areas for the fat and water peaks at 1.3 ppm and 4.7 ppm, respectively, and for the fat olefinic peak at 5.4 ppm. The fat signal included contributions from unresolved resonances from the methyl ($\approx$ 0.9 ppm), methylene chain ($\approx$ 1.3 ppm), allyclic ($\approx$ 2.1 ppm) and protons in α position to the carbonyl group ($\approx$ 2.3 ppm). T_2 values were determined for water and fat by fitting the obtained peak areas with TE = 40 ms and 70 ms to monoexponentially decaying functions of the form $M_o\exp(-TE/T_2)$, where M_o is the extrapolated peak area for TE = 0 ms. The fitting was carried out by minimizing the sum of the squares of the difference between the fitted curve and the measured data in MATLAB. Fat to water ratios were determined by dividing the M_o value obtained for fat by that of water. Statistical significance of differences between fat to water ratios and water and fat T_2 values from the L3, T7, and C4 vertebrae were determined by employing two-tailed paired t-tests. A p-value of less than 0.05 was considered statistically significant.

Results: Figure 1 shows the voxel placements in the L3, T7 and C4 vertebrae for one of the volunteers. The L3 spectra obtained with TE = 40 and 70 ms from one of the volunteers with a relatively large amount of fat is displayed along with the fitted spectra in Fig. 2. The means (standard deviations in brackets) of fat to water ratios and fat and water T_2 values calculated for each vertebra over all the volunteers (20 volunteers for L3 and T7, 19 for C4) are as follows: 0.364 (0.144) for L3, 0.261 (0.097) for T7 and 0.191 (0.091) for C4. On average, the fat to water ratios decline going from L3 to C4. However, since fat to water ratios vary depending on age and sex (1-4) the different vertebral ratios were compared to each other within each volunteer using a two-tailed paired t-test. P-values of less than 0.001 were obtained when comparing fat to water ratios between L3 and T7, L3 and C4, and T7 and C4 vertebra indicating significant statistical differences between the ratios measured in the different vertebral bodies. The fat to water ratio in the T7 vertebra is approximately 75 % of that of the L3 vertebra on average in each volunteer, while the fat to water ratio in the C4 vertebra is about 57 % that of L3. The mean fat T_2 values calculated for each vertebra are in the vicinity of 55 ms. Paired t-tests indicate that T_2 differences between the L3 and T7 vertebrae are not significant, whereas the fat T_2 constants of the C4 vertebra are significantly different compared to those of the T7 and L3 vertebrae (p-value < 0.01). Specifically, the fat T_2 in C4 vertebrae is 17 % and 23 % lower than in the L3 and T7 vertebrae, respectively, on average in each volunteer. Average water T_2 constants are similar for the different vertebral locations, namely, about 23 ms. The only paired t-test which shows a statistical difference is between the C4 and T7 vertebrae (p-value $\approx$ 0.04). The C4 water T_2 is approximately 6 % lower than the corresponding T7 value on average for each volunteer.

Discussion: The decrease in fat to water ratios as we move from lumbar to cervical spine is in agreement with previous lumbar vertebrae observations (3,5,6) which report a reduction in fat fractions by a few percent higher up the lumbar spine towards L1. Red to yellow bone marrow conversion as a result of aging result in increased fat fractions and Ref. (3) suggests that the conversion may be taking place from the inferior vertebrae (towards L5) upwards in a "peripheral to axial" manner. The lower fat and water T_2 values in the C4 vertebra maybe due to the higher bone mineral density of cervical spine compared to thoracic and lumbar spine (7-8); higher T_2 values have been previously reported in regions of lower bone density (9).

Conclusion: To our knowledge, this is the first study to investigate variations in fat to water ratios and fat and water T_2 values in lumbar, thoracic and cervical spine of healthy volunteers. We found a trend of decreasing fat to water ratios going from lumbar to thoracic to cervical spine and lower T_2 values in cervical spine. The characterizations will aid in quantifying changes that take place in diseased vertebrae.

References:

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Figure 1: Voxel locations in L3, T7 and C4 (left to right) vertebrae of a volunteer

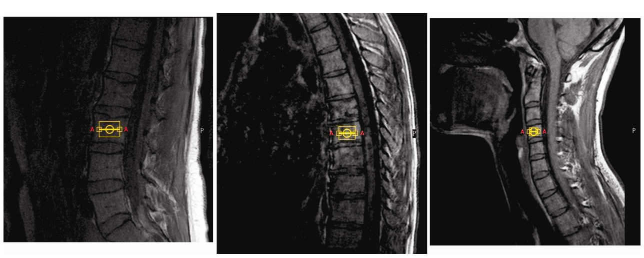

Figure 2: Spectra acquired from L3 vertebra of one of the volunteers. The dashed spectra are the peak fitted spectra.