Evaluation of bone quality in calcanei of young and postmenopausal women through ADC measurement

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Target audience: Translational researchers interested in noninvasive assessment of bone quality

Purpose: Even though bone mineral density (BMD) has been the accepted standard for osteoporosis diagnosis, BMD has a low predictive value on patients’ risk for future fractures. Thus, new approaches for examining patients at risk for developing osteoporosis would be desirable. Recently, a porous system model suitable for investigating the microstructural properties of cancellous bone, by using diffusion MRI, was described and experimentally corroborated2,3,4. The model is based on the schematic representation for which water is more prevalent in the boundary zone while fat occupies primarily the central zone of each cancellous bone pore. Therefore water component in bone marrow diffuses in the interstitial space between bone and fat and its diffusion process is affected by the strong internal magnetic field gradient (IMFG) located at the interface bone-water. With the development of osteoporosis cancellous bone pores became more and more large and interconnected, increasing water apparent diffusion coefficient (ADC). Aim of the present work is to test ADC measurement on cancellous bone as a new potential indicator to evaluate the bone quality. Toward this goal, ADC measurement and its reproducibility was performed together with diffusion signal behaviour study as a function of b value, and correlation between ADC, marrow fat content (Mfc), and BMD and age.

Methods and Materials:

Subjects Fifty-eight calcanei in total were studied: nine from young healthy (mean age 33±10, age range 22-45 y), nine from postmenopausal healthy (mean age 64±6, age range 53-70 y), twenty from osteopenic (mean age 63±8, age range 50-75 y), and twenty from osteoporotic (mean age 66±7, age range 52-74 y) women were investigated at 3.0T. Postmenopausal volunteers were classified as healthy osteopenic or osteoporotic subjects, according to their vertebral T-score values obtained by using QCT. This study was approved by the local Ethics Committee and written informed consent was obtained in all cases before study initiation.

Experiments ADC in calcanei was evaluated from DWI images acquired in a single-sagittal section of the calcaneus using a 3T Allegra Siemens scanner. A spin-echo segmented echo-planar imaging (EPI) sequence (repetition time, TR=1500 ms, echo time, TE=96 ms; field of view, Fov=192x192 mm2; matrix, 128x128; epi factor, 7; diffusion gradient along the anterior-posterior direction) was employed in a first phase by using five different b-values (b=0, 1000, 3000, 5000, 8000, 10000 s/mm2). Then b=8000 s/mm2 and TE=80 ms was selected to collect data from all subjects. A volume of interest (voxel size, 15x15x15 mm3) in the central zone of the calcaneus was also selected for collecting 1H spectra (TR/TE=5000/22 ms; number of signal-averages NS=52) using a single-voxel spectroscopy PRESS sequence. Analysis: ADC values were obtained from DWI images, using the relation \( I_{water} = I_{0} \cdot \exp(-b \cdot ADC) \), where \( I_{0} \) and \( I_{water} \) are the mean signal intensities at \( b=0 \) s/mm2 and \( b=8000 \) s/mm2. All 1H spectra were analyzed using the LC Model method. Mfc was calculated for all subjects according to the following equation:

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Mfc = \left( \frac{I_{fat} - I_{water}}{I_{fat} + I_{water}} \right) \cdot 100,
\]

where \( I_{water} \) is the water peak area (at about 4.7 ppm) and \( I_{fat} \) is the sum of partially overlapping lipid peaks.

All measured variables in the calcaneus were compared between the three bone density groups and the young women group by a one-way analysis of variance (one-way ANOVA). Pearson correlation coefficients (r) were calculated to assess linear correlation between pairs of variables for all subjects and for all subjects belonging to each bone density group. A P value less than 0.05 was considered statistically significant.

Results and discussion: All ADC values of cancellous bone show a lower ADC value due to the presence of IMFG, as confirmed by simulations. Their short time and long time reproducibility is acceptable. Young healthy women are characterized by the lowest ADC values (3.6±0.4)×10^-11 m^2/s and the lowest standard deviation. ADC values were significantly lower in healthy (ADC=[4.1±0.7]×10^-11 m^2/s) than in osteopenic (ADC=[5.2±1.3]×10^-11 m^2/s) and osteoporotic (ADC=[6.7±1.3]×10^-11 m^2/s) subjects. Moreover ADC values significantly discriminate between osteopenic and osteoporotic women. The highest ADC values in osteoporotic group may be a consequence of pore enlargement and increase in interconnections between adjacent pores in the trabecular bone network due to formation of perforations of trabecular plates. A significant linear correlation was found between ADC and T-score values (Fig. 1) and no-correlation was found between ADC and age in postmenopausal subjects. On the other hand, a significant correlation (n=53) was found between ADC and age when all healthy subjects (young and postmenopausal women) are considered. Although Mfc values didn’t discriminate between different bone density groups (according to previous results)2, results displayed in Fig. 2 show a dependence of ADC values on Mfc in osteoporotic and healthy group. In healthy subjects, the positive linear correlation may indicate both trabecular-bone network and metabolic changes due to normal aging. Please note that for highest Mfc, ADC values of all healthy and osteoporotic women move to a common value. This result is in agreement with the cancellous bone model previously described3 and suggests that postmenopausal women characterized by a low fat content can be better classified as healthy, osteopenic and osteoporotic women on the basis of ADC results in calcaneus. Because the yellow bone marrow increases with aging, graph in Fig. 2 suggests that, ADC investigations could be also useful in pediatric investigations of pathologies involving changes in trabecular-bone density.

Conclusion: In the present study, we have quantified the compartment-specific water ADC changes in calcaneal bone of healthy subjects characterized by a large age range of young and osteoporotic women and healthy patients at 3T employing DWI and MRS techniques. ADC data from human calcanei shows the ability of diffusion measurement to obtain complementary information, compared to those provided by BMD for investigating cancellous bone quality.

References:


Fig. 1. ADC vs T-score measured in osteopenic (green triangle), osteoporotic (red triangle) and healthy (blue triangle) women.

Fig. 2. ADC vs Mfc measured in young healthy (light blue square) and healthy (blue triangle), osteopenic (green triangle), osteoporotic (red triangle) postmenopausal women.