# Assessment of cancellous bone quality through NMR diffusion measurement of water in trabecular bone microstructure and bone marrow fatty acids quantification

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Progress in understanding the pathogenesis of bone fragility and in performing a correct osteoporosis diagnosis is hampered by the poor accessibility of bone for microstructural investigation in vivo. Bone densitometry performed by means of dual-energy x-ray absorptiometry, is a noninvasive and low cost method for the quantification of bone mineral density (BMD), but it cannot provide information about trabecular bone rearrangement and organic components, that are details strictly linked to bone strength [1,2].

Even though BMD has been the accepted standard for osteoporosis diagnosis, it has a low predictive value on patients' risk for future fractures [2]. More specifically, bone strength is determined by the overall bone quality, a term that incorporates all the factors that determine how well the skeleton can resist fracturing, such as microarchitecture, accumulated microscopic damage, the quality of collagen and bone marrow, the size of mineral crystals, the physiologic activity of the skeletal cells and the rate of bone turnover [3].

Thus, new approaches for investigating subjects at risk for developing osteoporosis would be desirable.

In this regard, Magnetic Resonance (MR) diffusion weighted imaging (DWI) methodologies allow in vivo investigation of microstructural tissue features, by probing biological water motion on the micrometer length scale, which is orders of magnitude smaller than the macroscopic DWI image resolution.

Recently, a porous system model suitable for investigating the microstructural proprieties of cancellous bone by diffusion MR Imaging was described and corroborated by experiments [4-7]. The model is based on the schematic representation for which bone marrow water is more prevalent in the boundary zone while fat occupies primarily the central zone of each cancellous bone pore. Moreover, to better understand the mechanisms underlining osteoporosis development, bone marrow fatty acids are quantified [8].

In this work, Magnetic Resonance diffusion measurements were performed at 3T magnetic field in 60 woman (aged 22-75 y) characterized by different BMD (classified as healthy, osteopenic and osteoporotic subjects) and correlation between diffusion parameters, marrow fatty acids content (Mfc), BMD, and subjects' age were investigated. Monte Carlo simulations of water diffusion in different synthetic trabecular bone structures were conducted to elucidate the influence of magnetic susceptibility and Mfc on diffusion measurement in bone and corroborate clinical results. This investigation, which aims at finding an effective method for early osteoporosis diagnosis, is carried out in collaboration with orthopedic, physiologists and radiologists of Tor Vergata University, IRCCS Santa Lucia of Rome and Pennsylvania University (USA).

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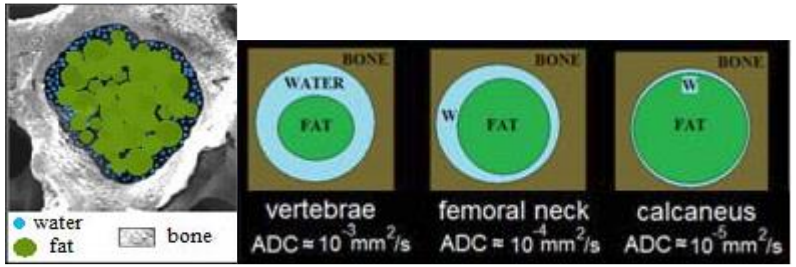
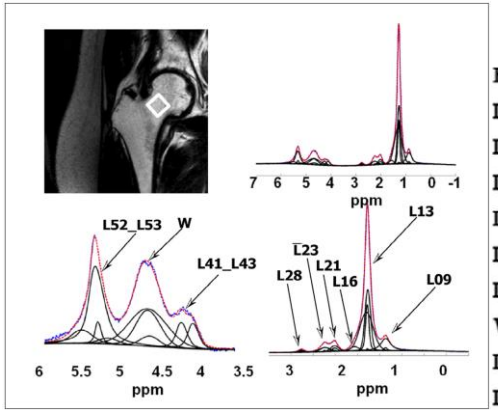



Figure 1 - The porous model suitable for obtaining microstructural information in cancellous bone by using diffusion. ADC is the apparent diffusion coefficient quantified by diffusion weighted MR tecniques




| Resonance acronym | and name |
|---|---|
| L09 | methyl protons |
| L13 | methylene protons |
| L16 | methylene protons β to COO |
| L21 | methylene protons α to C=C |
| L23 | methylene protons α to COO |
| L28 | diallylic methylene protons |
| W | Water |
| L41 and L43 | Glycerol |
| L52 and L53 | Olefinic double bond protons |

Figure 2 - Example of 1H-MRS spectra obtained in femoral neck of healthy subject and lipid quantification The T2-weighted image of femur shows the position of voxel (white square) used to collect spectra

**Table 1**
**MR data in calcaneus and femoral neck of healthy, osteopenic and osteoporotic group**

| Parameter | Skeletal site | 1 (H) | 2 (OPE) | 3 (OPO) | *P* Value (1 vs 2) | *P* Value (2 vs 3) | *P* Value (1 vs 3) |
|---|---|---|---|---|---|---|---|
| Mfc (%) | Calcaneus | 86.44±4.70 | 88.01±3.32 | 87.50±2.00 | ns | ns | ns |
| ADC ($*10^{-10}$ m$^2$/s) | Calcaneus | 0.40±0.08 | 0.52±0.15 | 0.68±0.16 | ** | * | *** |
| Mfc(%) | Femoral neck | 73.42±5.34 | 80.14±7.78 | 83.86±4.94 | * | ns | *** |
| ADC ($*10^{-10}$ m$^2$/s) | Femoral neck | 4.12±0.56 | 2.12±1.14 | 2.15±0.41 | *** | ns | *** |

Data are mean ±SD. n=number of subjects. ns ($P \geq 0.05$); *($P < 0.05$); **($P < 0.01$); ***($P < 0.001$).