Quantitative Bone Quality Assessment Using Digital Topological Analysis and FDT on 7T MRI

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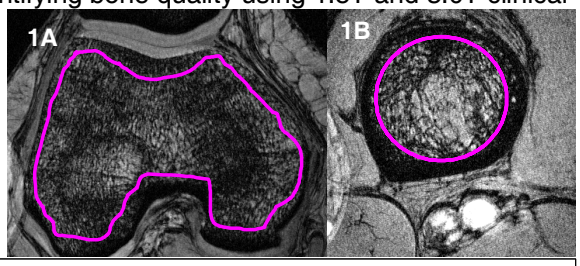
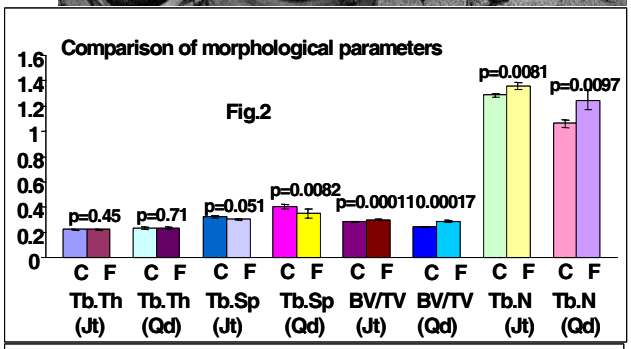
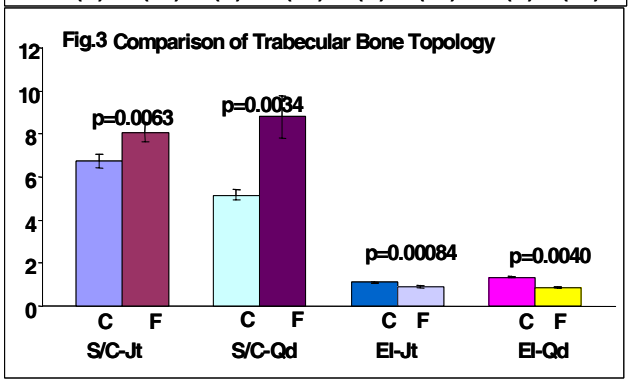
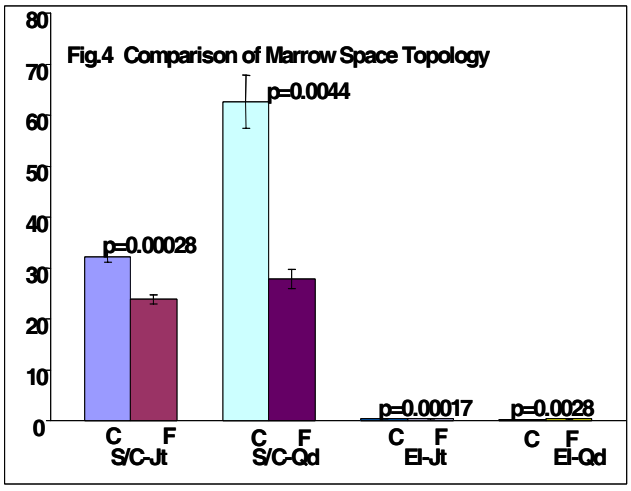
Introduction: Osteoporosis is the most common degenerative disease that is characterized by loss of bone mass and deterioration of structural integrity of trabecular bone (TB). TB is network of interconnected plates and struts interspersed with marrow. Fracture risk is only partly explained by diminished bone mineral density and the remaining half of bone fragility is relatable to alteration of bone quality. Skeletal stress response was first described in Wolff's law and has recently become an important area for *in-vivo* research. Bone quality plays an important role on the pathogenesis of Osteoarthritis (OA) has lead to a desire to understand the cartilage/bone interactions in greater detail [1].
High resolution (micro) MRI based approaches have been applied for quantifying bone quality using 1.5T and 3.0T clinical scanners [2-5]. However, low signal-to -noise ratio (SNR) and long acquisition times are major issues at low field systems. The purpose of this work was to demonstrate the feasibility of quantitative bone quality assessment at ultra high field system (7T) with high SNR and shorter scan time. This study measures bone quality of US Olympic fencers and correlates with age & body mass index (BMI) matched controls via 7T MRI.



Methods: 7 human subjects (4 fencers from 2004 US Olympic Fencing Team and 3 age & BMI matched controls, mean age 25 years) were explicitly recruited for *in-vivo* studies. A 7.0T whole body MR scanner (Siemens Medical Solutions, Erlangen, Germany) was employed for all MRI experiments using a quadrature knee coil (18 cm diameter, transmit-receive).We utilized a high-resolution 3D-FLASH sequence [TR/TE=20/4.5 ms; flip angle, 10°; total number of sections =80 for knee joint (with 195μmX195μmX1000μm resolution) and 50 for quadriceps (with 156μmX156μmX1000μm resolution); bandwidth 130 Hz/pixel; one signal acquired] to acquire all MRI data. Bone volume fraction (BVF) images were computed from MRIs using a local marrow intensity computation approach without requiring a thresholding. These BVF images were used by Fuzzy Distance Transform (FDT) [6] and Digital Topological Analysis (DTA) [7] algorithms. FDT was applied for trabecular thickness (Tb.Th) and trabecular separation (Tb.Sp) while surface-curve- ratio (S/C), erosion-index (EI) etc) were derived using DTA for assessing bone quality. The topological parameters were computed for both TB and marrow space (MS) (an inverse of the BVF image). All statistical comparisons were performed using student's paired t-tests to determine the statistical differences between two groups.







Results and Discussion: Representative axial MR images of knee (A) and quadriceps (B) region were shown in **Fig.1.** The comparison of morphological parameters [Tb.Th, Tb.Sp, BV/TV and Tb.N] between two groups [fencers (F) vs controls (C)] can be seen in **Fig.2**. Mean values of all the morphological parameters were statistically significant between two groups ($P<0.05$), except Tb.Th. The comparison of trabecular bone and marrow space topology (S/C and EI) were statistically significant between fencers vs controls in both knee joint and quadriceps regions ($P<0.05$) (**Fig.3 &4**). The fencers group had more plate-like structure (increased S/C) and increased network connectivity (decreased EI) in both knee and quadriceps regions.

Conclusion: The preliminary results demonstrate that the 7T MRI is suitable for detecting topological differences between TB of fencer's knee and that of age & BMI matched controls. For the first time, in this study, DTA has been applied to quantify topology of marrow space for assessing bone quality. The current study clearly suggests that the TB distinctly responds to mechanical loads (e.g: US Olympic fencers) especially in the lower extremities compared to sedentary controls.

References:1) Beuf O et al Arthritis Rheum 2002; 46: 385-93. 2) Wehrli FW et al NMR in BioMed. 2006;19:731-64. 3) Boutry N et al Radiology 2003; 227:708-17. 4) Ma J et al MRM 1996; 35: 903-10. 5) Banerjee S et al JMRI 2005; 21: 818-25. 6) Saha PK et al CVIU 2003; 86: 171-90. 7). Saha & Chaudhuri 1996; 63: 418-29.