Interrelationships between 3T-MRI-, 64-section-MDCT-, and micro-CT-derived trabecular bone structure parameters: a study in cadavers

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Target audience: Diagnostic radiologists

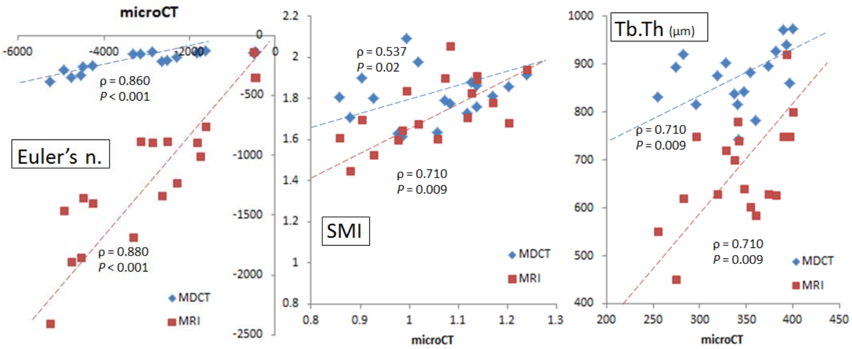
Purpose: Bone mineral density (BMD) measurements alone do not provide sufficient discrimination between patients with and without increased fracture risk[1]. The concept of "bone quality" was introduced by the National Institutes of Health Consensus Conference on Osteoporosis in 2001[2]. Bone quality refers to the "sum total of characteristics of the bone that influence the bone's resistance to fracture". Beyond BMD, these characteristics include measures of trabecular microarchitecture. With the introduction of 3T MR scanner systems, multiple studies have demonstrated that 3T MR-derived trabecular measures reflect the true structure of bone[3]. The current study was performed to assess the relationship between 3T MR- and MDCT-derived measurements, using micro-CT measures of the spine as the gold standard. Comparisons were based on measurements of intact human cadaver vertebrae.

Methods: Fresh human vertebrae were obtained from the cadavers of 3 males (age range, 85–93 years). Intact vertebrae were scanned by micro-CT (TOSCANER; Toshiba, Japan), 64-section MDCT (VCT; GE Healthcare, and 3-T MRI (Signa HDxt 3T; GE Healthcare). L2 and L3 vertebral bodies were scanned at the central, adjacent upper, and adjacent lower 6-mm thickness locations, resulting in a total of 18 measurement sites. MR imaging was performed using an 8-channel phased-array head coil. Axial (3D SPGR: flip angle, 20°; slice thickness, 0.8 mm; matrix, 512×512; NEX, 4; FOV, 8 cm; bandwidth, 31.25 Hz; TR, 11.5 ms; TE, 4.2 ms; scan time, 40 min) scans were prescribed, resulting in a voxel size of 150×150×100 µm. Scanning parameters for MDCT were 120 kVp, 750 mA, and 64×0.625 collimation, resulting in a voxel size of 200×200×160 µm. Scanning parameters for micro-CT used the default settings of the manufacturer (80 kVp, 100 µA), resulting in a voxel size of 70×70×100 µm. Finite element analysis and microstructural analysis were performed using a 3D image analysis system (TRI/3D-BON; RATOC System Engineering, Tokyo, Japan). Failure load (FL) was determined to the level that induced fractures in 2.8% of trabecular bone. Stiffness was also obtained. The following trabecular microstructural parameters were obtained: trabecular bone volume fraction (BV/TV); trabecular thickness (Tb.Th); number of trabeculae (Tb.N); trabecular separation (Tb.S); Euler's number (E); degree of anisotropy (DA); and structure model index (SMI). Median values were determined for each measurement and the Kruskal-Wallis test was used to test for significant differences between MRI/MDCT-derived and gold-standard measurements. Relationships between MRI/MDCT-derived trabecular parameters and gold-standard micro-CT measurements were evaluated and compared using Spearman's correlation coefficient (ρ).

Table 1. Results of Spearman rank correlation for MRI/MDCT-derived and micro-CT-derived trabecular bone parameters.

		MRI		MDCT	
	Parameter	ρ	P	ρ	P
Morphology Metric	BV/TV (%)	0.657	0.04	0.719	<0.001
	Tb.N (/mm^3)	0.597	0.03	0.629	0.005
	Tb.Th (µm)	0.519	0.20	0.420	0.08
	Tb.S (µm)	0.740	0.01	0.780	<0.001
Non-metric	SMI	0.710	0.009	0.537	0.02
	Euler's number	0.880	<0.001	0.860	<0.001
	DA	0.820	0.007	0.920	<0.001
Mechanics	Stiffness (N/mm)	0.623	0.006	0.620	0.004
	Failure load (N)	0.640	0.008	0.767	<0.001

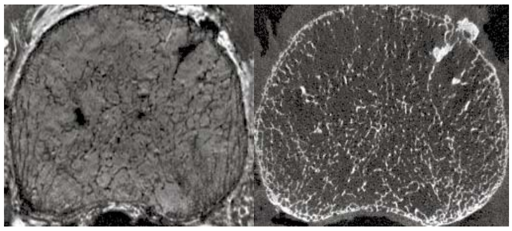
Figure 1. Graph of MRI/MDCT- and micro-CT-derived trabecular bone parameters. Linear regression curves were plotted.



Results: Among all parameters, BV/TV, Euler's number, Tb.Th, SMI, FL and stiffness were overestimated and Tb.N was underestimated by MRI/MDCT. No significant differences were found between MRI- and MDCT-derived measurements in Tb.N, BV/TV, or SMI. Additionally, no significant differences were seen between the three groups in DA or Tb.S.

The correlation of indices measured by MRI/MDCT for morphology and mechanics (against micro-CT) are presented in both Table 1 and Figure 1. MRI/MDCT-derived measurements correlated moderately with gold-standards, with the exception of Tb.Th. MRI-derived Euler's number and Tb.Th showed regression slopes nearer to unity than those derived from MDCT. Correlations between metric parameters, including BV/TV and Tb.N, and gold standard tended to be better by MDCT than by MRI. Non-metric parameters, including SMI and Euler's number, showed better correlations between MRI and micro-CT than between MDCT and micro-CT.

Figure 2. Matched cross-sectional images of the L3 vertebral body obtained with 3-T MRI (left) and micro-CT (right) at the central positions.



Discussion: This study demonstrated the feasibility of 3-T MRI for determining trabecular measures. Under- and overestimation of parameters by MRI may be related to low spatial resolutions and susceptibility artifacts, resulting in diminishment of thin trabeculae. Regarding MDCT, under- and overestimation of parameters may be related to low spatial resolutions and diminishment of thin trabeculae during the process of thresholding. Reasonable correlations were found for many parameters; however, the spatial resolutions of MDCT/MRI did not permit accurate results in measurement of metric indices. This was particularly true for Tb.Th due to the relatively thin trabeculae. On the other hand, non-metric measures were determined well by MRI, which was likely due to an apparent increase in trabecular networks caused by susceptibility artifacts.

Conclusion: Our study demonstrated that 3-T MRI is a tool capable of assessing trabecular bone. Both 3-T MRI- and MDCT-derived measures showed significant correlations with micro-CT-derived parameters, suggesting that these two methodologies assess similar and complementary characteristics of bone.

References: 1. Schuit SC, van der Klift M, Weel AE, et al. Fracture incidence and association with bone mineral density in elderly men and women: the Rotterdam Study. Bone 2004;34(1):195–202. 2. Osteoporosis prevention, diagnosis, and therapy. JAMA 2001;285(6):785–95. 3. Krug R, Carballido-Gamio J, Burghardt AJ, et al. Assessment of trabecular bone structure comparing magnetic resonance imaging at 3 Tesla with high-resolution peripheralquantitative computed tomography ex vivo and in vivo. Osteoporos Int 2008;19(5):653–61.