

Subregional bone mineral density and bone volume fraction in whole human vertebrae: concurrent analysis using DXA and micro-CT

E.Perilli^{1,2}, A.M. Briggs³, J.D. Wark⁴, S. Kantor⁴, I.H. Parkinson^{1,2}, N.L. Fazzalari^{1,2}

¹ Bone and Joint Research Laboratory, SA Pathology and Hanson Institute, Adelaide, South Australia, Australia, egon.perilli@health.sa.gov.au

² Discipline of Anatomy and Pathology, University of Adelaide, Adelaide, South Australia, Australia

³ School of Physiotherapy, Faculty of Health Sciences, Curtin University of Technology, Perth, Western Australia, Australia

⁴ Department of Medicine, University of Melbourne, Bone & Mineral Service, Royal Melbourne Hospital, Melbourne, Victoria, Australia

Aims

Vertebral fracture risk of patients is usually evaluated using dual-energy X-ray absorptiometry (DXA) of the lumbar spine, together with clinical factors. Posterior-Anterior (PA) projections are usually performed, with areal bone mineral density (BMD) measured within the whole vertebral body. However, bone distribution and thus bone strength vary within the vertebra^{1,2}. Subregional BMD measurements using lateral-projection DXA scanning modality might be more informative about vertebral fragility. Nowadays, micro-computed tomography (micro-CT) allows three-dimensional structural characterization of entire bone segments, non-destructively and at high resolution³. To assess the capability of lateral-projection DXA to determine subregional variations in bone distribution, this study examined human vertebrae first by DXA and then by micro-CT.

Method

Eight human cadaver spines were examined (mean age at death 78±10 years). These were immersed in a water bath and scanned by DXA in PA and in lateral projections (densitometer Hologic QDR4500, Hologic, Waltham, MA, USA). Subregional BMD analysis was performed in lateral projection of the L2 vertebrae, with the examination area divided via software in three subregions of interest (superior, central, inferior).

The L2 vertebrae were then dissected and entirely scanned by micro-CT (17.4 µm pixel size, Skyscan 1076, Skyscan Kontich, Belgium). The micro-CT volume of interest comprised the trabecular bone of the entire vertebral body³. It was divided via software into three analogous subregions with equal height (superior, central, inferior), from which bone volume fraction (BV/TV) was assessed (software CTAnalyser, Skyscan).

Results

For both DXA and micro-CT, the values of the whole vertebral body showed statistically significant differences compared to the subregions ($p < 0.01$, one-way ANOVA for repeated measures, fig. 1 and 2).

Statistically significant differences between the subregions were found for both BMD and BV/TV, with the inferior subregion having higher values than the superior subregion ($p < 0.05$, paired t-test, fig.1 and 2).

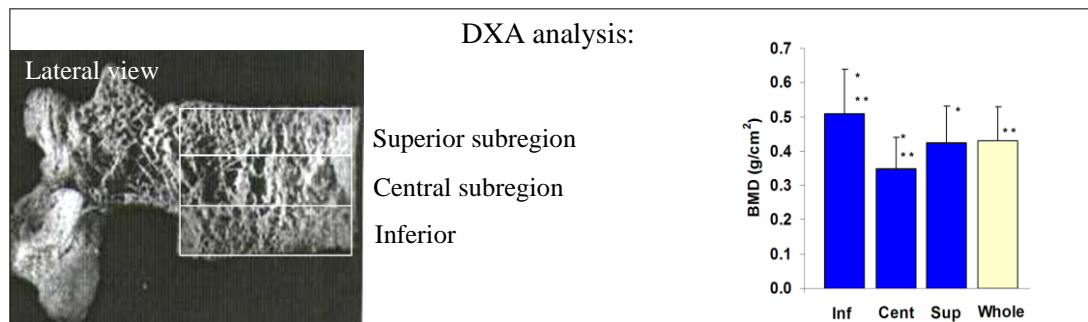


Figure 1: Schematic diagram of the three vertebral subregions, and bar plot of BMD measured by lateral DXA in these subregions (mean \pm SD for each subregion).

*Stat. sign. differences between all subregions ($p < 0.05$, paired t-test). **Stat. sign. differences between inferior and central subregion, and whole vertebral body ($p < 0.05$, paired t-test).

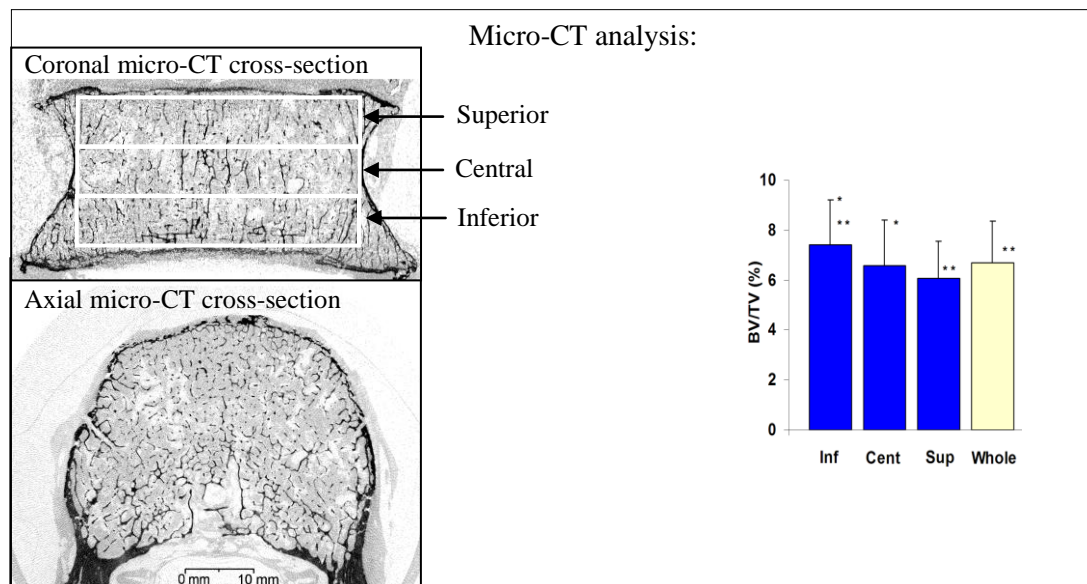


Figure 2: Micro-CT images a human vertebral body (17.4 μm pixel size), and bar plot of BV/TV measured in the three vertebral subregions (mean \pm SD for each subregion).

*Stat. sign. differences between inferior and central subregion ($p < 0.05$, paired t-test). **Stat. sign. differences between inferior and superior subregion, and whole vertebral body ($p < 0.05$, paired t-test).

The BMD measured by lateral-projection DXA over the whole vertebrae was significantly related to the total BV/TV measured by micro-CT ($R^2 = 0.59$, $p < 0.05$, fig. 3), whereas BMD measured in PA-projection DXA was not ($R^2 = 0.16$, $p = 0.33$, fig.3).

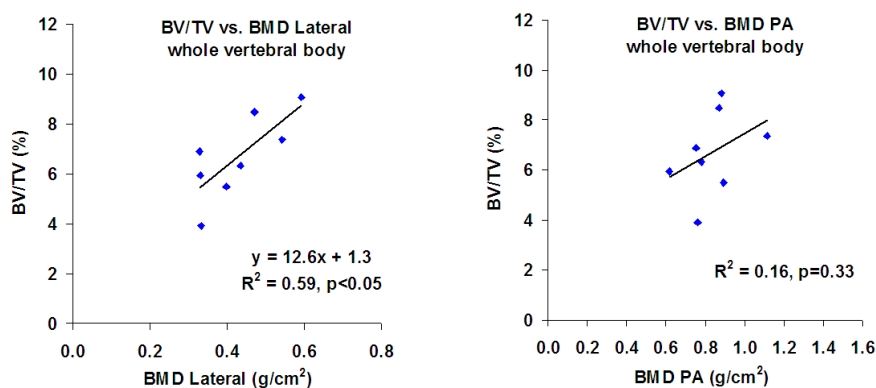


Figure 3: Scatter plot of total "BV/TV vs. BMD". (Left) BMD measured in lateral projection, (Right) BMD measured in posterior-anterior (PA) projection. While total BMD measured by lateral-projection DXA was significantly related to the total BV/TV, the BMD measured in the PA projection was not.

In the central subregion, the linear regression 'BV/TV vs. BMD' had the highest coefficient of determination ($R^2 = 0.80$, $p < 0.01$), compared to the inferior and superior subregion (figure 4).

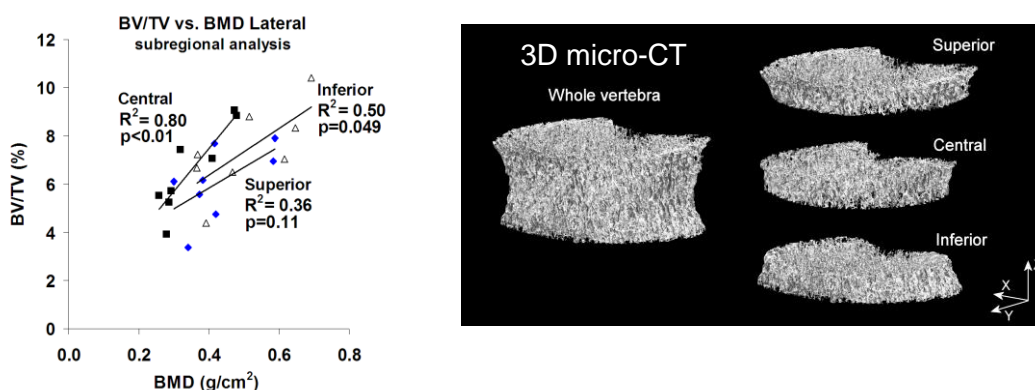


Figure 4: (Left) Scatter plot of “BV/TV vs. BMD” measured in the three vertebral subregions. The central subregion showed the highest determination coefficient in the regression ($R^2 = 0.80$, $p < 0.01$). (Right) 3D reconstruction of the trabecular bone volume of a human vertebral body obtained by micro-CT, subdivided into 3 subregions (voxel size 17.4 μm).

The finding of BMD being lowest in the central subregion (fig. 1), whereas BV/TV being lowest in the superior subregion (fig. 2), can be explained by the inclusion of the vertebral endplates in DXA analysis. In the central subregion, which does not contain the endplates, the regression “BV/TV vs. BMD” shows the highest regression coefficient (figure 4, left).

Conclusion

Differences in the bone parameters between the whole vertebra and the subregions were found by both lateral-projection DXA and micro-CT, both techniques showing higher values in the inferior compared to the superior subregions. This study shows that, in contrast to BMD assessed using PA-projection DXA scanning, measurements using lateral-projection DXA in the L2 vertebra are significantly related to BV/TV assessed via micro-CT. In particular, subregional BMD measurements are highly related to trabecular bone volume fraction in the central part of the vertebral body. These findings support lateral-projection DXA examination as a valuable modality for improving the evaluation of vertebral fragility.

References:

1. Briggs AM, Greig AM, Wark JD, "The vertebral fracture cascade in osteoporosis: a review of aetiopathogenesis" *Osteoporos Int*, 18(5), 575-584, 2007
2. Gong H, Zhang M, Yeung HY, Qin L, "Regional variations in microstructural properties of vertebral trabeculae with aging" *J Bone Miner Metab*, 23, 174-180, 2005
3. Briggs AM, Perilli E, Parkinson IH, Wrigley TV, Fazzalari NL, Kantor S, Wark JD, "Novel assessment of subregional Bone Mineral Density using DXA and pQCT and subregional microarchitecture using Micro-CT in whole human vertebrae: applications, methods, and correspondence between technologies" *J Clin Densitom*, 13(2):161-174, 2010