Inhomogeneity of osteoporotic human vertebral properties

INHOMOGENEITY OF OSTEOPOROTIC HUMAN VERTEBRAL PROPERTIES

+*Terlouw, M A; +*Rietbergen, B van; *Lochmüller, E-M; **Eckstein, F; +*Huiskes, R
* Gynaecology Hospital, LMU, München, Germany; ** Musculoskeletal Research Group, Institue of Anatomy, LMU München, Germany
+*; Department of BioMedical Engineering, Eindhoven University of Technology, PO-Box 513, 5600 MB Eindhoven ,The Netherlands
b.v.rietbergen@tue.nl

Introduction

Osteoporosis is known to deteriorate mechanical and morphological properties of cancellous bone. The extent of this process is usually evaluated on small excised specimens. In these studies it is usually assumed that the results are not critically depending on the actual sampling location. Recent studies, however, have demonstrated that considerable variation in bone morphology can exist within vertebrae [1]. This raises a few questions. First, to what extend can the results of such sampling studies be affected by the inhomogeneity of the bone properties if the sampling location is not precisely controlled? Second, how does the variation within a vertebrae relate to the variation that can be expected between subjects? Third, can the trabecular core exhibit symmetry in its three orthogonal planes?

In this study we aim at finding answers to these questions with the use of recently developed high-resolution imaging and finite element techniques that enable an accurate and three-dimensional determination of structural and mechanical parameters at different locations within human vertebrae. Using these methods and ANOVA analysis, vertebral inhomogeneity is investigated for a large number of subjects.

Methods

A micro-CT system was used to create high-resolution (60-80 µm) 3-D reconstructions of 43 excised vertebrae taken from 28 donors (average age 79 years) from two sites (thoracic vertebra 10 and lumbar vertebra 4). Within the core of each vertebral body eight volumes of interest, VOI, with sides of 6 mm were identified, one for each octant (Figure 1).

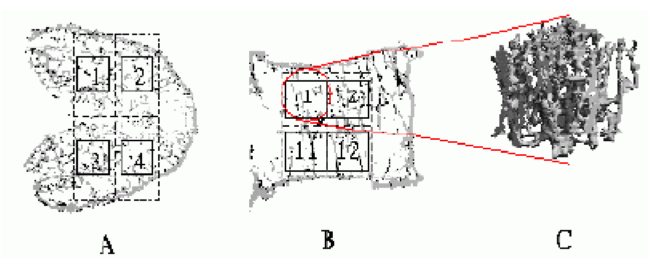

Figure 1. *Positioning of the eight VOI*

For each VOI the following morphological parameters were calculated in a real 3D manner: volume fraction (*BV/TV*), trabecular thickness (*Tb.Th*), architectural anisotropy (*DA*) and connectivity density (*Conn.D*). In addition, micro- finite element (micro-FE) analysis [2] was used to determine the elastic properties of each VOI. Mechanical parameters that were used in this study are the longitudinal and transversal modulus (E_{33} and E_{11} respectively) and one of the shear moduli G_{12}.

To quantify the variation of a parameter within a vertebrae the RMS average of the coefficient of variation, $\overline{CV}_{within}$, was calculated in the following way:

$$\overline{CV}_{within} = \sqrt{\sum_{i=1}^{N}\left(\frac{SD_i}{\bar{x}_i}100\%\right)^2}$$

with SD_i the standard deviation and $\bar{x}_i$ the mean of the 8 observations of variable x (as calculated for the 8 VOI's) for vertebrae i.

In a similar way, the variation of a parameter between subjects was quantified as:

$$CV_{between} = \frac{SD}{\frac{1}{N}\sum_{i=1}^{N}\bar{x}_i^2}100\%$$

with SD the standard deviation of the N observations of $\bar{x}_i$.

Each analysis was performed separately for the T10 and L4 vertebral level.

To investigate the symmetry of the vertebrae, analysis of variance (ANOVA) was performed for three side factors: AP-side (Anterior or Posterior), SI-side (Superior or Inferior) and LR-side (Left or Right). For each tests, the average value of the four VOI's located on one side of the tested symmetry plane was compared to the average of the four VOI's on the other side of the plane. Since the data was not normally distributed, non-parametric analyses were performed.

Results

The within variance as quantified by the $\overline{CV}_{within}$ parameter ranged from 9% to 115% (Fig. 2 (top)). The variance for the mechanical parameters was larger than that for the morphological parameters. Also, the variance for the L4 vertebrae was larger than that for the T10 vertebrae.

The between variance as quantified by the $CV_{between}$ parameter ranged from 7% to 91% (Fig. 2 (bottom)). As with $\overline{CV}_{within}$, variance was larger for the mechanical parameters and larger for L4 than for T10.

The ANOVA analysis revealed significant differences between the Anterior and Posterior sides and between the Superior and Inferior sides for all variables except Tb.Th.

No significant differences were found between the Left and Right side, except for some of the parameters, but in these cases differences were small.

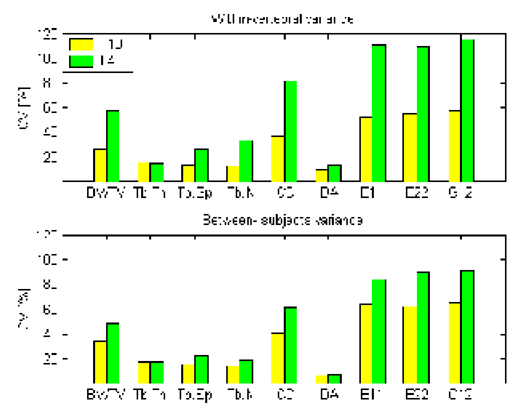

Figure 2. *Variance within the T10 and L4 vertebrae (top) and and between subjects (bottom)*

Conclusions and discussion

The results demonstrate that the variance in cancellous bone morphological and mechanical parameters within vertebrae from elderly can be considerable. This indicates that the exact location of the VOI plays an important role. The between-subjects variance was about as large as the within-vertebrae variance. This indicates that, if the sample position is not well controlled, the sensitivity of the sampling procedure is not good enough to detect differences between subjects. Finally, the results demonstrate that no Anterior-Posterior or Superior.-Inferior symmetry can be assumed. Left-Right symmetry, on the other hand, is a reasonable assumption.

The fact that higher CV values were found for the L4 than for the T10 vertebrae can be due to several factors. First, it is possible that this is due to the lower resolution used for the L4 vertebrae. Based on earlier resolution studies, however, this is not very likely. It is also possible that this is due to the fact that the L4 vertebrae are larger. Hence the VOI's in the L4 are further apart.

References

[1]. Banse et al. (2001), Bone, 28:563
[2] van Rietbergen et al. (1995) J.Biomech, 28:69