Inhomogeneity of osteoporotic human vertebral properties

Citation for published version (APA):

Document status and date:
Published: 01/01/2005

Document Version:
Publisher’s PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:
• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher’s website.
• The final author version and the galley proof are versions of the publication after peer review.
• The final published version features the final layout of the paper including the volume, issue and page numbers.

Link to publication

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

• Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
• You may not further distribute the material or use it for any profit-making activity or commercial gain
• You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license above, please follow below link for the End User Agreement:
www.tue.nl/taverne

Take down policy
If you believe that this document breaches copyright please contact us at:
openaccess@tue.nl
providing details and we will investigate your claim.

Download date: 15. Jan. 2022
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, Institute 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 vertebra 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. The 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 (E₃3) and E₁₁ respectively) and one of the shear moduli G₁₂.

To quantify the variation of a parameter within a vertebrae the RMS average of the coefficient of variation, CV_within, was calculated in the following way:

\[ CV_{\text{within}} = \sqrt{\frac{\sum_{i=1}^{N} \left( \frac{SD_{x}}{\bar{x}} \right)^{2}}{N}} \]

with SD the standard deviation and \( \bar{x} \) the mean of the 8 observations of variable \( x \) (as calculated for the 8 VOI’s) for vertebra \( i \). In a similar way, the variation of a parameter between subjects was quantified as:

\[ CV_{\text{between}} = \frac{SD}{\sqrt{\sum_{i=1}^{N} \left( \frac{SD_{x}}{\bar{x}} \right)^{2}}} \]

with SD the standard deviation of the N observations of \( \bar{x} \).

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 test, 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 \( CV_{\text{within}} \) 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 variance between subjects as quantified by the \( CV_{\text{between}} \) parameter ranged from 7% to 91% (Fig. 2 (bottom)). As with \( CV_{\text{within}} \), 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.

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 variation. 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