Contribution of Trabecular Microarchitecture and its Heterogeneity to Biomechanical Behavior of Human L3 Vertebrae

INTRODUCTION:
Low bone mineral density (BMD) is a strong risk factor for vertebral fracture in osteoporosis. However, BMD explains only 40 to 70% of the variation in trabecular bone strength [1]. In addition, many fractures occur in people with normal BMD [2]. Besides BMD, trabecular microarchitecture improves prediction of bone mechanical behavior [3, 4]. Trabecular microarchitecture heterogeneity has been previously described [5, 6], however there is limited information about its contribution to vertebral fragility.

The aim of this study was to assess the contribution of trabecular microarchitecture and its heterogeneity to mechanical behavior of human lumbar vertebrae.

METHODS:
L3 vertebrae taken from 21 fresh donors (11 males and 10 females, respectively aged 75±10 years and 76±10 years) were analyzed and destructively tested in uniaxial compression. Lateral-BMD (g/cm²) was measured using dual energy X-ray absorptiometry (DXA; Delphi W®, Hologic, MA, USA). 3D trabecular microarchitecture (bone volume per tissue volume (BV/TV), structural model index (SMI), trabecular separation (Tb.Sp*), trabecular thickness (Tb.Th*) and trabecular number (Tb.N*)) was assessed without model assumption using high-resolution peripheral quantitative computed tomography (HR-pQCT; X-Trem CT®, Scanco Medical, Switzerland) with a nominal isotropic voxel size of 82 µm.

Trabecular microarchitecture heterogeneity was assessed using two 8.2 mm diameter virtual biopsies (one anterior and one posterior vertically cored in 3 zones: superior, middle and inferior) and on the whole vertebral trabecular area (Figure 1.). Heterogeneity of trabecular microarchitecture was evaluated by:
1) the ratio of antero-posterior BV/TV (BV/TVratio); 2) the coefficient of variation of the vertical 3 zones parameters (BV/TVcv,); and 3) the distribution expressed by the standard deviation of Tb.Sp* on virtual biopsies (Tb.Sp*SDant) and on the whole trabecular area (Tb.Sp*SD).

Vertebral stiffness (N/mm), failure load (N) and work to failure (N.mm) were measured on the whole vertebral body using a servohydraulic testing machine (Schenck RSA-250®, Germany) under displacement control at 0.5 mm/s until failure.

All parameters had normal distribution, after log transformation for work to failure and BV/TVratio. Parametric tests (Student t-test, ANOVA, Pearson's correlation coefficient, stepwise and multiple regression analyses) were performed using SPSS 12.0® software.

RESULTS:
Mean values for L3 vertebral biomechanics, as well as trabecular architectural parameters are given in Table 1.

Microarchitectural features differed significantly between the anterior and posterior virtual biopsies for all parameters (p<0.007 to 0.04), except for SMI and Tb.Th*. Vertebral failure load was mainly explained by microarchitectural parameters of the anterior region as assessed by stepwise regression analysis (i.e., in the equations, failure load = anterior and posterior microarchitectural parameter, the second one was always out of model). As a result, we studied vertical heterogeneity on the anterior biopsy. Significant vertical heterogeneity was found for BV/TV and SMI (respectively, p-value = 0.0001 and 0.021, ANOVA).

Table 1. L3 vertebrae bone trabecular architectural parameters – (mean, (SD)), * p<0.05 posterior core vs anterior core.

DISCUSSION:
Consistent with previous studies, we found heterogeneity of vertebral trabecular microarchitecture [3]. Importantly, bone mass parameters (i.e.; BMD or BV/TV) in combination with trabecular microarchitecture heterogeneity (i.e.; BV/TVratio, BV/TVcv, and Tb.Sp*SDant or Tb.Sp*SD) were independent predictors of vertebral mechanical behavior, together explaining up to 74% of the variability in the prediction of vertebral fragility. Our data imply that the measurement of trabecular microarchitecture heterogeneity may enhance prediction of vertebral fracture risk.

REFERENCES:

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