In-silico prediction of vertebral body strength

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Introduction

- Due to osteoporotic bone loss, vertebral bone fractures can occur in the elderly [Fig. 1]
- Currently, bone mineral density (BMD) measurements are used to diagnose osteoporosis
- However, BMD is not an unique predictor for bone strength
  - For a better prediction, the internal trabecular architecture must be accounted for as well [2]
  - Bone trabecular architecture can be quantified by morphological and/or mechanical parameters

Fig 1 *Healthy (top) and crushed spine segments*

Hypothesis

A relationship that includes BMD and trabecular bone *mechanical* parameters can better predict vertebral bone strength than statistic relationships that include BMD and trabecular bone *morphological* parameters.

Methods

Step 1

- An unique data set of 43 excised vertebrae was analysed both experimental and through high-resolution imaging.
  - Vertebrae taken from 28 donors (average age 79 years), at two levels (thoracic (T10) and lumbar (L4)).

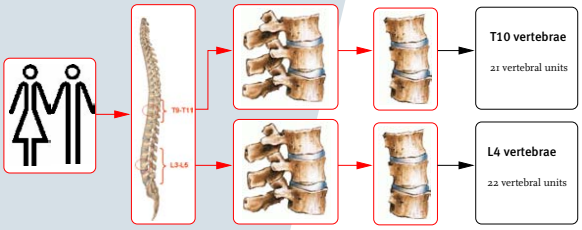

Fig 2 *Excise spinal units*

Step 2

- Each vertebrae was scanned on a μ-CT system.
  - High resolution (60-79 μm) 3-D reconstructions.
- Parametric measurements were concentrated in eight cubic VOI's, located within the trabecular core.
  - Numerical DXA analysis provided BMD.
  - Morphology analysis provided volume fraction (BV/TV), trabecular measures ($Tb.Th, Tb.Sp, Tb.N$), architectural anisotropy (DA) and connectivity density ($Conn.D$).
  - Mechanical analysis provided Young's moduli (E_{ij}), shear moduli (G_{ij}) and Poisson's ratios (ν_{ij}).

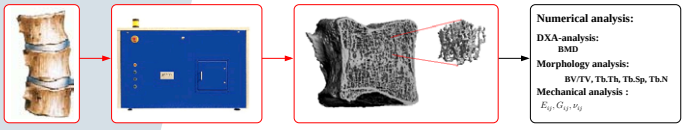

Fig 3 *Numerical analysis of trabecular properties.*

Step 3

- Each vertebrae was compressed at the LMU in Munich [1].
  - Each segment was embedded in bone cement.
  - Failure load was defined at 25% height reduction.

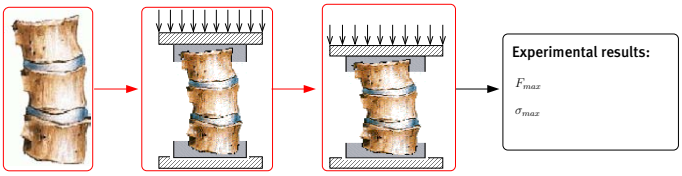

Fig 4 *Experimental compression of spinal unit*

Statistics

- Three Multiple Regression model were built:
  1. BMD
  2. BMD + One or more morphology parameters.
  3. BMD + One or more mechanical parameters.
- Selection of the model-parameters was based on the largest significant increase of R^2.

Results

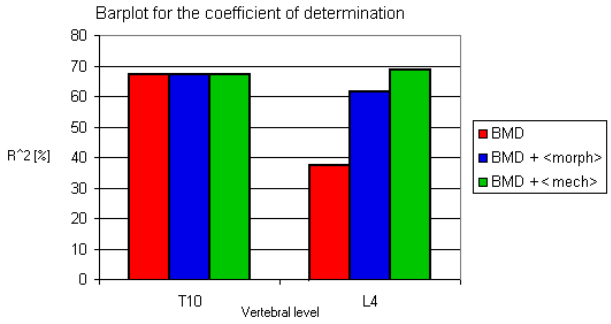

Figure 5 *Barplot of R^2-values for each model*

- The prediction of the L4 vertebral strength improves significant (37% to 61 %) by adding $Tb.Sp$ to BMD
- The prediction of the L4 vertebral strength improves more significant (37% to 68 %) by adding E_{33} and G_{13} to BMD
- The prediction of T10 vertebral strength cannot be improved.

Conclusions & Discussion

- The hypothesis that the prediction of the vertebral failure load can be improved more by using *mechanical* rather than *morphological* parameters in addition to BMD holds for L4 only.
  - BMD alone is enough to predict the T10 failure load.
- The used image resolution was considered to be at the minimum required level [3].
  - This resolution cannot be obtained with whole-body CT-scanners, yet.
  - Eventually, these methods might be applicable in-vivo.

References:

[1] *Bürklein et al.(2001) Bone, 28(5), 563-571*
[2] *McCreadie and Goldstein (2000) JBMR, 15(12), 2305-2308*
[3] *Ulrich et al. (1998) J Biomech 31, 1187-1192*