

## In-silico prediction of vertebral body strength

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# 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)).

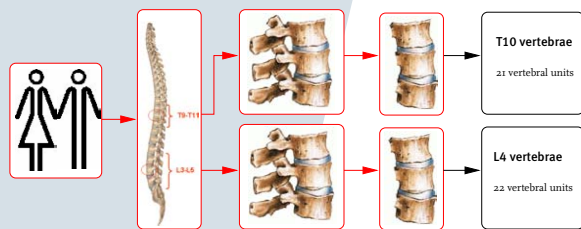


Fig 2 Excise spinal units

### Step 2

- Each vertebrae was scanned on a  $\mu$ -CT system.
  - ▷ High resolution (60-79  $\mu$ m) 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 ( $\nu_{ij}$ ).

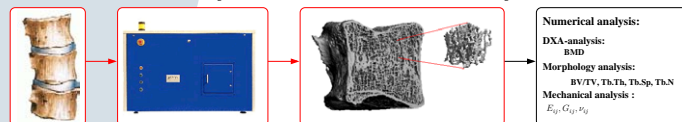


Fig 3 Numerical analysis of trabecular properties.

### 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.

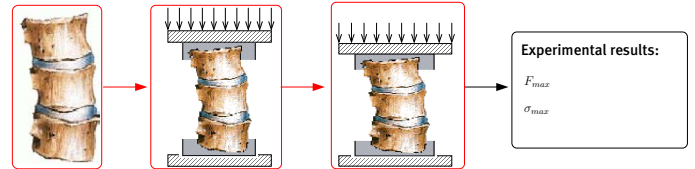


Fig 4 Experimental compression of spinal unit

## 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

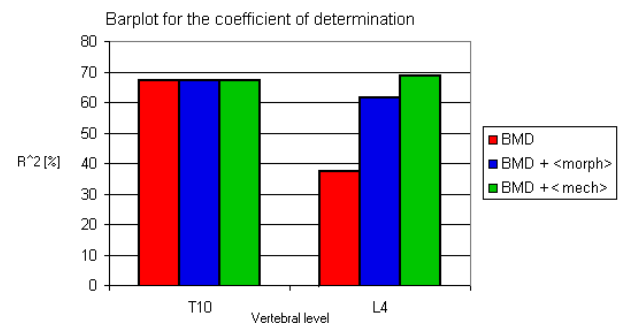


Figure 5 Barplot of  $R^2$ -values for each model

- 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