Bone Volume Fraction Measured via Micro-CT Imaging is a Predictor for Hydraulic Permeability and Elastic Modulus of the Trabecular Bone of Human Lumbar Vertebral Bodies

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BACKGROUND

- Subject specific computational modeling requires knowledge of both geometry and mechanical properties of vertebrae
- **CT imaging** is a mildly invasive approach providing **accurate geometry of the vertebra**
- Radiographic density of the **CT images** have been **related to** the elastic properties of bones, such as the **Young's modulus (E)** [1-3]
- The **cancellous bone** is **porous** and saturated with **fluid**. The **hydraulic permeability (K)** controls fluids and solutes **transport**, and vertebral **mechanical behavior** [4]
- Previous studies measured hydraulic permeability in vertebrae [5, 6], trying to relate K to bone mineral density with unsatisfactory results [6]

OBJECTIVE

- To establish a quantitative empirical relationship among cancellous bone morphological characteristics and the vertebral mechanical parameters K and E

METHODS

- Vertebrae L1, L2 and L3 of bone mineral density 0.895, 1.043 and 1.106 g/cm^2 from 54 y.o. white male
- Specimen preparation illustrated in Figure 1
- During indentation, vertebral slices were embedded in PBS and compressed via servoelectric testing system (Instron E3000, Norwood, MA) equipped with a 5kN load cell
- The relaxation over time of the reaction force of the sample was curve-fitted with the solution of a finite element model simulating the indentation test on a vertebral slice
- The computational model schematized the vertebra as a biphasic material with an isotropic elastic solid phase and fluid flow governed by Darcy's law with constant hydraulic permeability
- The shape of the computational domains were similar to those of the samples tested, and included ~27,000 tetrahedral elements
- Micro-CT images collected at 50kV with 18μm resolution.(SkyScan1176, Bruker BioSpin Corp., Manning Park, MA)
- An open source image processing software (ImageJ, NIH) was used to measure the bone volume fraction (BV/TV), defined as ratio of bone volume to total volume
- A regression analysis was performed to determine whether BV/TV is a predictor for K and E

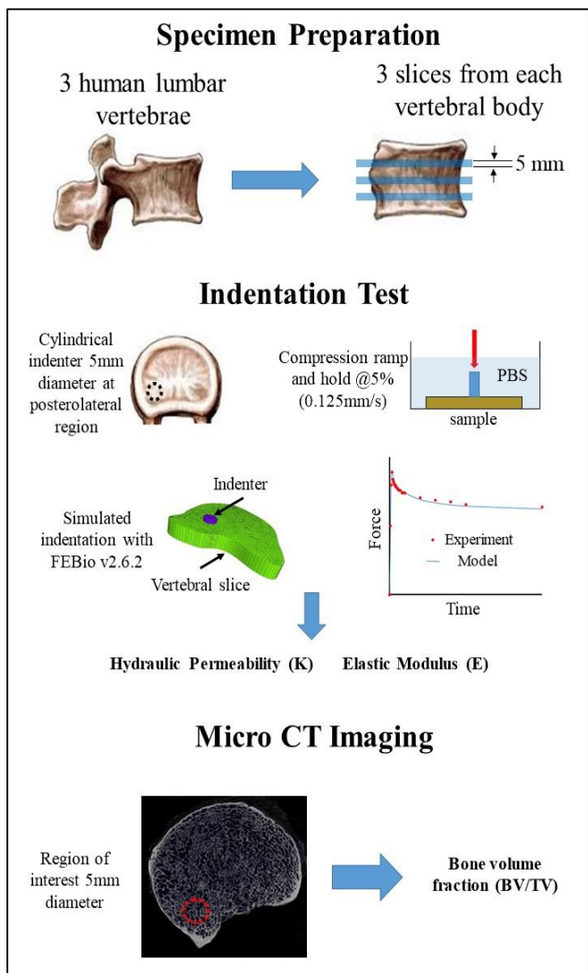

Figure 1. Specimen preparation and testing methods

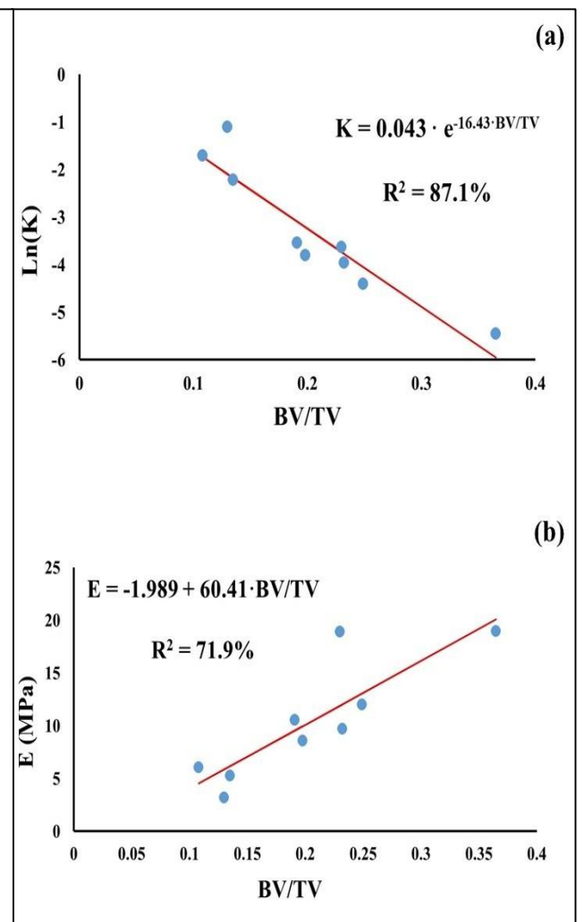

Figure 2. Simple linear regression of **(a)** hydraulic permeability **(K)**, and **(b)** elastic modulus **(E)** as a function of bone volume fraction **(BV/TV)**

RESULTS

- Values of K and E ranged from $4.3 \cdot 10^{-3}$ to $3.3 \cdot 10^{-1}$ mm$^4 \cdot$N$^{-1} \cdot$s^{-1} and 3.18 to 18.95MPa, respectively. The BV/TV values ranged from 0.11 to 0.36. The regression analyses are shown in Figure 2

DISCUSSION

- The magnitude of **K** was in **good agreement** with those reported for other trabecular bones [7]
- The values of E were smaller than those reported for vertebrae [8]
- Regression analyses indicated strong relationships among BV/TV, and K and E. As previously observed [6], the relationship between K and BV/TV is non-linear

SIGNIFICANCE

- **Bone volume fraction** is a parameter measurable with the mildly invasive technique of micro-CT imaging analysis that can provide **crucial information** on the **mechanical behavior of the human lumbar vertebrae**
- If similar results can be obtained with a routine diagnostic method as CT scanning, this study paves the way to the possibility of accurately modelling human vertebrae in vivo

REFERENCES: [1] Zannoni et al., Med Eng Phys, 1999. [2] Hodgkinson and Currey, J Mater Sci, 1992. [3] Rice et al., J Biomech, 1988. [4] Isaksson et al., J Biomech, 2006. [5] Ochia and Ching, J Biomech Eng, 2002. [6] Baroud et al., J Biomech, 2004. [7] Ochoa and Hillberry, Proc Ann Meet ORS, 1992. [8] Hernandez, Handbook of Biomaterial Properties, 2016.