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HUMAN FEMORAL CANALICULAR NETWORK HYDRAULIC CONDUCTIVITY

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Introduction

Bone poroelasticity models are of great importance to estimate bone lacunocanalicular (LCN) fluid flow. The fluid circulating within this interconnected porous network is known to be involved in the osteocytes-based bone remodeling. During loading, pressured gradients developed in the canaliculi promoting a shift in fluid velocity. This shift can be sensed by the osteocytes and converted into a biological signal. But current models of bone LCN fluid flow are mainly on a simplify geometry of the LCN. more particularly, the LCN permeability, which partly depends on the network morphology, implemented in the models remains an estimated value. This is mainly due to the submicrometric and complex nature of the LCN, making it difficult to characterize in 3D. Recently, the LCN from 27 human femoral diaphyses has been observed through synchrotron radiation based nano-computed tomography [1]. Through this data set, the local canalicular morphology can be characterized over large volumes. In the present study, the local intrinsic permeability has been measured on this data set based on some morphological parameters in order to provide more realistic values for bone poroelastic models.

Materials and methods

Human femoral bone samples were scanned at the ESRF (Grenoble, France) on the beamline ID16B. The LCN was segmented on volumes of $256 \times 256 \times 200 \mu\text{m}^3$ (voxel size = 100 nm) using a following a previous published protocol [2]. The LCN was converted into a network topology, describe by cells (lacunae), links (canaliculi), and nodes (points of canaliculi ramification) [3]. A watershed algorithm was then applied, based on the 3D distance map from the canaliculi, in order to create a tessellation in which each unit cell contains one canalicula.

The intrinsic permeability was calculated for each canalicula as [4]:

$$\kappa = \frac{\eta_f \delta^2}{32\theta^2} (m^2)$$

where η_f (%) is the local volume fraction of the canalicula in its unit cell, δ is the canalicula averaged diameter, and θ is the canalicula tortuosity (geodesic length / straight length).

Results and discussion

Currently, 6 volumes have been processed, the other are still under processing. The table provides a summary of the intrinsic permeability values.

Param / Volumes	V1	V2	V3	V4	V5	V6
Age (y.o.)	50	66	73	74	74	75
$\kappa_{\text{mean}} (10^{-20} m^2)$	6.1	3.3	2.6	3.2	2.5	2.8
$\kappa_{\text{median}} (10^{-21} m^2)$	7.1	4.2	3.5	3.8	3.2	4.9
$\kappa_{\text{max}} (10^{-17} m^2)$	7.2	6.1	2.4	18.1	2.4	3.6
$\kappa_{\text{min}} (10^{-23} m^2)$	3.5	7.4	3.5	0.6	3.8	0.3
$\kappa_{\text{SD}} (10^{-19} m^2)$	7.1	1.8	1.4	5.5	1.4	1.4

Table: Summary of ages and intrinsic permeability values for 6 volumes.

The obtained results show that the LCN permeability is ranged from 10^{-17} to $10^{-23} m^2$, with an averaged value around $10^{-20} m^2$. Such values are in accordance with what has been estimated in the past, using simplified geometry [5]. But while previous models of LCN fluid flow used a single permeability value, the current results show that LCN permeability is highly heterogeneous (see figure). In this regard, LCN fluid velocity may depend on the location around the Haversian canal. It has to be noticed that the nature of the pericellular matrix also influences the canaliculi permeability but is not considered in the current study.

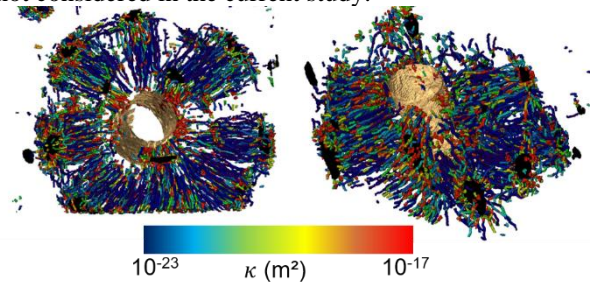


Figure: Permeability distribution on one isolated osteon. Lacunae are in black.

This new mapping of LCN intrinsic permeability will allow to develop new models of LCN fluid flow based on a realistic morphological descriptor in 3D dimensions.

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