

PERMEABILITY IN OSTEOPOROTIC BONE: A microCT STUDY

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INTRODUCTION

Osteoporosis is a disease characterized by an increase in bone resorption that leads to decreased bone mineral mass density and a deterioration of bone tissue micro-architecture. These structural changes translate to an increase in bone fragility and fracture [1]. Intertrabecular bone marrow plays an important role in bone remodeling and transporting cells, oxygen and nutrients that are critical in biological processes [2]. When studying the role of intertrabecular bone marrow in osteoporosis, one of the important parameters is the trabecular bone permeability. Permeability depends on the tissue porosity and the interconnectivity of the trabeculae, and it can vary according to the anatomic site [3]. Because permeability is related to the microstructure of the trabecular tissue, we hypothesize that it can be quantified using micro-computed tomography (μ CT) images. The objectives of this project were 1) to develop an experimental method to measure permeability using trabecular bone cubes and 2) to correlate the permeability with μ CT morphological outcomes.

METHODS

Cubic specimens (1cm^3) of trabecular bone ($n=15$) from cadaveric human tibiae were used for the project. The cubes were scanned with μ CT (Scanco Medical μ CT 35, Switzerland) using a nominal resolution of $20\mu\text{m}$. The μ CT images were segmented and evaluated to obtain the outcomes for: bone volume fraction (BV/TV), trabecular thickness (Tb.Th), trabecular separation (Tb.Sp), and trabecular number (Tb.N). Subsequently, marrow was removed from the trabecular bone by immersing the specimen in a solution of soap and distilled water, then placing the cube in an ultrasonic bath for 60 min. A constant head permeameter was custom designed and built to measure the permeability. The time required to fill a 500 mL beaker with water was measured using a chronometer. Each cube was tested 5 times to determine precision. Permeability was then calculated using Darcy's Law and an analysis of correlation between the permeability and the μ CT outcomes were conducted.

RESULTS

The mean permeability measured from the 15 cubes was $5.3 \times 10^{-6} \pm 3.0 \times 10^{-6} \text{ m}^2$. The maximum standard deviation found for the five trials was $9.1 \times 10^{-8} \text{ m}^2$ (Fig.1). The correlation coefficients between μ CT outcomes and permeability were 0.338, 0.002, 0.366, 0.590 for BV/TV, Tb.Sp., Tb.N., and Tb.Th. respectively; with the last one being statistically significant.

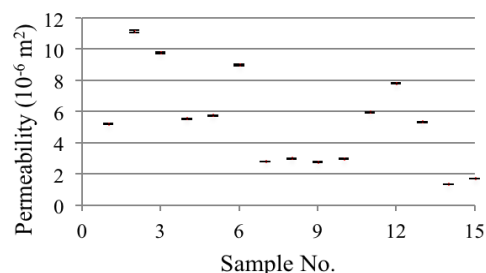


Figure 1. The permeability of the cubic human bone specimen sample ($n=15$). The largest relative error found based on 5 trials was 1.42%. The figure is used to express the precision of the permeameter as well as the variability in permeability obtained through the samples.

DISCUSSION AND CONCLUSIONS

An experimental device to measure trabecular bone permeability was successfully developed. The low standard deviation of the permeability demonstrated the excellent precision of the permeameter. The high variability of the permeability among samples is consistent with the heterogeneity of the microarchitecture of the trabecular bone cubes. The largest correlation between permeability and a morphometric variable was found for Tb.Th. The other μ CT outcomes exhibited low correlation. These results suggest that permeability cannot be determined using only morphometric variables. However, the μ CT images can be used to reconstruct the real architecture of the bone samples and perform more advance studies (i.e finite element modeling). Utilizing a permeameter that generates precise measurements combined with μ CT images will offer information of sample specific permeability. This information will then provide new insights into the transport functions and biomechanics of trabecular bone. Due to the prevalence of fractures occurring predominantly in trabecular bone, this research can introduce new insights into fracture risk associated with bone diseases such as osteoporosis.

REFERENCES

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