PORE NETWORK ARCHITECTURE DETERMINES CORTICAL BONE ELASTICITY DURING GROWTH AND AGING

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Introduction

Cortical porosity is a major determinant of fragility fracture risk across life [1]. Haversian and Volkmann's canals are 'seen' as pores in 2D cross-section but fashion a dynamic network of interconnected channels in 3D [2], a quantifiable footprint of intracortical remodeling. Given the changes in bone remodeling with age [3], we hypothesized that the 3D architecture of the cortical pore network is age-dependent and influences its stiffness.

Methods

Cubes of cortical bone of 2 mm side-length harvested in the distal 1/3 of the fibula in 13 growing children (9M, 4F, mean age±SD: 12±4 yrs) and 16 adults (7M, 9F, 74±12 yrs) were imaged using desktop micro-CT (8 µm isotropic voxel size). Pores were segmented as a solid to assess pore volume fraction (Po.V/TV, %), number (Po.N, 1/mm), diameter (Po.Dm, µm), separation (Po.Sp, µm) and connectivity ConnD, 1/mm^3). Compression (C_{33}) and shear (C_{66}) elastic coefficients were derived by assessing waves velocity using ultrasonic measurements with a pair of 5 MHz transducers [4]. Spearman correlation coefficients (r') are reported when statistical significance reached ($p<0.05$).

Results

Pore volume fraction (Po.V/TV) did not differ between growing children and adults groups but originated from different architectural pattern (Figure 1). Relative to children, adults had 46% higher Po.N, 17% lower Po.Sp, 250% higher ConnD, 14% and 13% higher compressive (C_{33}) and shear (C_{66}) stiffness, respectively (All $p<0.02$).

In growing children, age was associated with a decrease in Po.V/TV (r'=-0.6) due to decreasing Po.N (r'=-0.5), Po.Dm (r'=-0.4) and increasing Po.Sp (r'=0.6). C_{33} and C_{66} were inversely correlated with Po.V/TV, Po.N and Po.Dm (r' ranging from -0.56 to -0.82). The correlation between C_{33} and ConnD remained significant after adjustment for Po.V/TV.

Among adults, age was associated with higher Po.V/TV (r'=0.7) originating from an increase in Po.N (r'=0.8), Po.Dm (r'=0.5) and a decrease in Po.Sp (r'=-0.8). C_{33} was inversely correlated with Po.V/TV (r'=-0.6), Po.N (r'=-0.6) and positively with Po.Sp (r'=0.7). Po.Sp remained correlated with C_{33} after accounting for Po.V/TV contribution (r'=0.6). No correlation was found between C_{66}, Po.V/TV or pore network architecture.

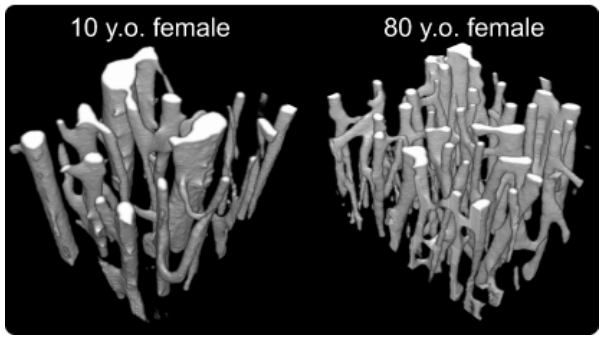

Figure 1: Examples of 3D reconstructions of the pore network imaged in cube of cortical bone cored in the distal part of the fibula in females. These reconstructions illustrate that the pore volume fraction while similar in the 10 y.o. girl and the 80 y.o. originate from different architectural patterns.

Discussion

We infer that changes in intracortical remodeling across life alter the distribution, size and connectedness of the channels forming cortical porosity. These alterations in pore network architecture participate in compressive stiffness impairments with aging, independently of the age-related increase in porosity.

References

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