A165 Pore Extractor: A Micro-Computed Tomography (micro-CT) Image Processing Suite for Characterizing 3D Pore Morphometry in Cortical Bone Tissue

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Learning Overview: This presentation introduces a novel suite of image processing macros for micro-CT images of bone tissue, for application in ImageJ and CT-Analyzer. The goals of this presentation are to: (1) visually demonstrate the completely automated extraction of cortical porosity, a predictor of spontaneous fracture risk; and (2) describe a novel structure-strain model for "normal" pore morphometry under low and high strain.

Impact on the Forensic Science Community: An eroded and highly porous cortex is a significant predictor of spontaneous fracture risk. Increased porosity can have age-associated (primary osteoporosis) or pathological/drug-associated (secondary osteoporosis) origins. To this end, this presentation develops a structure-strain model for expected changes in pore morphometry over the lifespan. By visualizing the porosity of bone tissue, forensic scientists can better assess a fracture's traumatic (e.g., forensic) or spontaneous (e.g., osteoporotic) origin.

On grayscale micro-CT images, it seems simple to automatically extract 3D pore networks by binarizing bone (lighter pixels) and pore space (darker pixels). However, small pores and faint trabecular margins are often excluded by a single global threshold for pixel brightness. Additionally, at high resolution, the endosteal boundary separating cortical and trabecular bone is ambiguous and commonly must be manually drawn on numerous image slices. In highly trabecular bones (e.g., femoral neck), it is particularly challenging to distinguish large "trabecularized" cortical pores from adjacent, similarly sized trabecular spaces. A workflow to overcome these challenges was developed using an age series of the matched right-side femoral neck and midshaft fourth rib, with one male and one female per decade from the 20s to the 90s. Whole cross-sections of each femoral neck and rib measuring 10mm long were scanned in a HeliScan™ micro-CT (6.4097µm voxels, 60kV, 80uA, exposure=0.4s).

The resulting image processing suite includes the following modules: (1) Slicewise Brightness/Contrast Adjustment (ImageJ): for each slice, picks the minimum threshold on the pixel brightness histogram that excludes soft tissue and includes bone tissue; (2) Adaptive Thresholding (CT-Analyser): removes mounting fixtures and image noise while isolating faint pores based on local pixel brightness; (3) Segment Merging (ImageJ): merges separately scanned regions of large cross-sections; (4) Marrow Bounding (CT-Analyser): draws the endosteal boundary by morphologically smoothing trabecular struts and cortical pore inclusions, extracting a filled cortical mask and isolated cortical pores; (5) Cortical/Trabecularized Pore Type Differentiation (ImageJ): separates cortical pores from "trabecularized" pores by comparing minimum diameter to marrow distance; (6) RCA/PI (ImageJ): calculates relative cortical area and parabolic index; and (7) Regional Division (ImageJ): divides each slice of the cortical mask into regional halves (rib) or octants (femoral neck).[1,2]

3D pore morphometry was calculated for each regional sub-division and pore type using CT-Analyser. The femoral neck displays an increasing compressive strain along a superior-to-inferior gradient, while the pleural and cutaneous cortices of the rib may display opposing high and low strain. This analysis found that pore networks appear morphologically optimized to resist local mechanical strain. High strain pores are significantly less densely populated, produce lower percentages of porosity, are less convergent with other systems, and are more longitudinally oriented. Such isolated systems would be less vulnerable to the initiation and propagation of microdamage than the dense, broad, and widely convergent pore network permitted in lower strain regions. Age-associated increases in porosity maintain this structure-strain optimization, excepting: (1) significantly lower pore separation due to pore convergence; and (2) superior-anterior coalescence of porosity in the female femoral neck.

This image processing suite fully automates cortical pore extraction from micro-CT images and can be modified for traditional histological cross-sections. This project also describes pore morphometry in high and low strain regions, aiding forensic scientists in identifying age-associated or pathological presentations of porosity that may signify spontaneous fractures.

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Reference(s):

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2. Epker, B.N., Frost, H.M. 1964. The parabolic index: A proposed index of the degree of osteoporosis in ribs. *J Gerontol* 19(4):469-73.

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