Quantification of Connectivity in Thin Bone Articulations

INTRODUCTION:
Articulations in thin bone structures in the human skeleton are understood to be fully fused by adulthood, with some structures achieving fusion up to the seventh decade. However, it has been shown that fractures commonly occur in adults at such articulation sites. While conventional computed tomography (CT) imaging techniques may be able to demonstrate a complete lack of fusion at such articulations, it can not provide information about the degree of connectivity which may occur across partially fused articulations. Micro-CT can be utilized to more closely examine these thin bone articulations and qualitatively has shown that thin bony articulations in the adult skeleton are not fully fused but rather connected in a network of bony projections.

Quantifying bone connectivity in 3D has been focused mainly in studying cancellous bone architecture and little attention has been paid to thin bone articulations. To date, methods of quantifying bone connectivity have been expressed in simple 2D approaches such as histological sections or 3D mathematical models using the Euler characteristic’s-topological approach. The Euler number has been the most commonly used approach for evaluating bone connectivity in 3D but there are major problems in using this method. In order to be able to use the Euler expression as a measure of the connectivity one must know the number of components plus the number of enclosed cavities within the structure. The Euler method is also dependant on the number of components and cavities and as such it can provide biased estimates of connectivity depending on the segmentation method.

We hypothesize that it is possible to quantify the degree of connectivity across thin bone articulations through the development of highly automated 3D image analysis techniques. The objective of this study is to develop a new automated method for quantifying the connectivity of bone in 3D with micro-CT imaging through a combination of skeletonization, thinning algorithms and 3D intensity maps.

METHODS:
A specimen (1.4x1x0.8cm) containing the coronal suture was excised from a preserved human craniofacial skeleton (age 75 years). A µCT scan of the specimen was acquired at a resolution of 14 µm (GE Explore Locus, General Electric Company). The raw scan images were reconstructed with the GE Explore Locus Recon utility yielding a stack of 970x660x1220 slices. An anisotropic filter was applied for 20 iterations to smooth the scan in order to reduce the noise and sharpen the bone boundaries. A sigmoid filter was also used to increase the contrast between bone and none-bone regions in each slice. The best fit sigmoid filter parameters for the scan were β = maximum intensity of none-bone region and α = the minimum intensity of none-bone region. The use of filters allowed for better image quality to identify the bone boundaries.

Using the skeletonization Module in AmiraDEV 4.1 the CT images were converted to Large Disk Data object and segmented to identify the boundaries of the bony projections and suture gap using intensity based threshold criteria. A 3D distance map for each voxel in the scan was produced by measuring the distances between each voxel and the nearest object boundary.

An automated thinning algorithm that uses both the segmentation and the 3D distance map was used to extract the center lines of the structure contained in the segmentation. The output of the thinning algorithm was used to generate a 3D surface of the bony projection’s central plane (Fig 1b). A bone density distribution map was generated for the specimen using the voxel intensity. The intensity map was used to generate a 3D surface of the bony projection’s central plane (Fig 1b).

Quantifying the connectivity of bone in 3D is crucial for evaluating bone architecture, strength and resistance to fracture. The quantification of the connectivity of thin bone structures may be important in understanding strain patterns and fracture modes across adjacent bones and provide useful information about the correlation between fractures at these sites and their connectivity. The method may further be applied to quantify the connectivity of trabecular bone or bone fragments during fracture healing and bone growth.

REFERENCES:
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