Introduction: Spinal fusion is the surgical process of adding bone graft between vertebral bodies of the spine to immobilize the joint space thereby eliminating joint instability. Clinical assessment of post-surgical spinal fusion is subjective and qualitative. Experimental assessment evaluates spinal fusion quantitatively through biomechanical testing and histological techniques. The geometry and material properties of a structure are predictive of the overall structure’s stiffness and deformation. Isolation of fusion mass structural geometry through noninvasive imaging techniques may provide structural information relevant in the clinical evaluation of spinal fusion efficacy. The objectives of this study were to develop an image processing protocol that isolated fusion mass volumes and spatial locations from existing peripheral quantitative computed tomography (pQCT) data files from sheep receiving spine fusions.

Materials & Methods: The data for this study were part of a previous study that evaluated the comparison of instrumented versus non-instrumented vertebral fusion with OP-1 (BMP-7) in an ovine model [1]. The biomechanical properties consisted of flexion/extension, lateral bending and torsion around the neutral zone of the spine. The pQCT data were received un-calibrated from the scanner (Picker International) (Fig. 1). Standard Digital Imaging and Communications in Medicine (DICOM) format transverse image files were obtained in sequential order at a slice thickness of 1.5mm and 2.0mm with a peak 130 kV at 175mA. The files had an in-plane resolution of (512x512) 35mm/pixel, 16-bit little-endian. Noise, electro-mechanical interference and photon attenuation within the pQCT data files, was not accounted for prior to initial image processing. Stabilizing implants (rods and pedicle screws) across the fusion site added additional challenges for image processing. Backscatter and high-density materials within the specimen data was affected by the true data representation in the pQCT data files and was removed from the original images with minimal loss of data of the true subject material (Fig.2).

The digital image processing was a multi-step process. A generic image processing foundation was created to handle both the instrumented and non-instrumented data. This was important for the effective non-invasive nature of this protocol. The first step was to create equally spaced dimensions within the existing pQCT data files. Cubic B-spline interpolation was performed to create equal dimensions in three-dimensional space. The image processing protocol involved an iterative (high/low) threshold segmentation process that used the histogram data to create masked regions of interest (Fig.3). For data without the pedicle screws, the iteration for segmentation worked most effectively from low to high histogram values. When pedicle screws were present, pre-processing steps, using histogram equalization, was necessary to correctly remove the screws and noise generated. These segmented regions became arithmetic/logic masks for the original image. A mask was created by separating the narrow histogram values, typical to pQCT and x-ray data, spread across the entire spectrum of gray-value choices (16-bit = 65536 shades of gray-value possible). The masks were converted to binary (black or white), and logic or arithmetic functions of (AND) and (OR) were used to separate unwanted parts of the original image without loss of information or data of the selected regions of interest (Fig.4). This new region became a higher-level mask, by following the same procedure as previously mentioned or a final area for data collection (Fig.5). Measurement of volume was achieved by summation of the isolated regions of interest within the individual slice pQCT data files. These regions of interest included the vertebral body, disk space and right and left side fusion mass across the spinal fusion region (Fig.6). Fusion mass volumes were normalized by dividing the total fusion mass volume of the right or left side by the total volume of bone for the vertebral bodies.

Discussion: Previous work in other applications using CT data, suggest vertebral bone strength could not be predicted using just apparent density values obtained from calibrated pQCT images [2-4]. Resolution from QCT was not accurate enough to deliver structural micro-architecture like micro-CT, MRI. Micro-CT has evaluated the structural component and material properties of cancellous bone with improved success over traditional CT bone strength correlations [5]. Isolation of structural macro-architecture of fusion mass may aid in defining a relationship between volumetric data and spinal fusion biomechanical properties. Future work will establish connections between fusion volume and location of fusion volume to the functional outcome from the biomechanical testing. This study established an efficient pre-and post-, non-invasive image processing protocol. This model used a simple volumetric, macro-architecture concept in connection with current digital image processing techniques to develop a cost effective tool for potential future non-invasive clinical applications.

References:

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