A VALIDATION STUDY: USING CT SCANS TO CALCULATE VOLUME, WEIGHT AND DENSITY

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INTRODUCTION

Virtual modeling is a rapidly growing pre-clinical evaluation tool in the biomedical field. Not only is it a non-invasive method to predict biomechanical behavior, but it can also be performed to gain insights before clinical applications [1-4], thus increasing the efficiency of the design process. Computerized Tomography (CT) scans can provide data on the shape and density distribution [5] of a tissue required for a virtual a model.

The purpose of this study was to determine an empirical relationship between the CT gray values (Hounsfield Units, HU) and the density of polymeric materials, and to apply this relationship to volumes constructed from the segmented CT data. These results were compared to physically measured volumes and weights.

METHODS

In this study, cylinders made from 8 materials were scanned with a clinical CT scanner: low density polyethylene, high density polyethylene, polymethylmethacrylate, polypropylene, Nylon 66, and low density polyurethane (LDPU) were 10 mm diameter by 7 mm height; and, high density PU (HDPU), and aluminum, were 10 mm diameter by 5 mm height. Each cylinder was measured and weighed prior to CT scanning (UW Hospital, 120 kV, 30 mA, 0.43 mm pixel size, GE LiteSpeed[16], GE Medical Systems). The cylinders were CT scanned with their axes oriented in a vertical direction.

The CT data were imported into Mimics 8.11 (Materialise, Ann Arbor, MI) software. Using the thresholding procedure "masks" were created which consisted of a group of pixels within the relevant range of HU's. The masks were not manually edited in this protocol. A mean value of HU was recorded for each material. Based on the masks, a 3D model of each material was constructed and its volume was determined. The 3D models were surface-meshed with triangles using Mimics and imported into MSC/Patran 2003 (MSC.Software, Santa Ana, CA) to create a volume mesh with tetrahedral-shaped elements, which was imported back into Mimics, to assign density to each element, based on the HU's. The volume mesh with assigned density was then re-imported into MSC/Patran 2003 to find its volume and weight.

RESULTS

An empirical relationship between HU and the polymeric densities (measured mass/volume) was derived (Figure 1). A mean of the absolute errors of 12% (-7%-19%) between the Mimics derived volumes and the measured volumes was found. The error between the Mimics and MSC/Patran volumes was insignificant. A comparison of the measured weights and densities to the MSC/Patran derived values found a mean of the absolute errors of 7% (-15% to -1%) and 12% (-17% to 20%), respectively, excluding the results from PU foams, which produced the largest errors (76% and 183%) on the weights of the HDPU and LDPU, respectively.

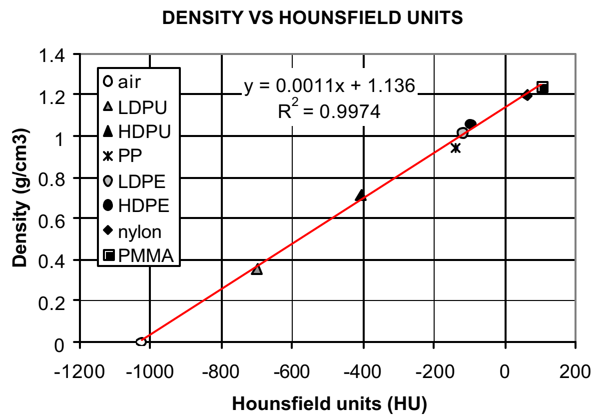

Figure 1: Density versus Hounsfield units for 7 polymers and air (ρ = 0 g/cm^3, at HU = -1024).

DISCUSSION AND CONCLUSIONS

The volume error of segmented models was due to CT scanning resolution which caused the cylinders to be slightly sectioned perpendicular to the scanning direction. Also, the thresholding procedure was imprecise at the base of the cylinders due to the material interfaces. The large errors in the weights and densities of LDPU and HDPU foams were caused by modeling them as a continuum. This result is particularly relevant to similarly derived models of trabecular bone and the study of its micro- and macro-mechanical properties.

CT scans of cylinders of various materials were used to construct 3D virtual models. A linear relationship (R^2 = 0.997) between HU and density for 7 polymers and air was used to assign density to a volumetric mesh. The measured and constructed properties (volume, weight and density) for the cylinders were compared, finding errors in weight and density of 7% and 12%, respectively, excluding the results from the LDPU and HDPU. The sources of error were: CT scanning resolution, thresholding at material interfaces, and modeling of foam on a macro-scale. The relationship between micro- and macro-mechanical properties needs to be further investigated.

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