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Computed tomography slice thickness and its effects on three-dimensional reconstruction of anatomical structures

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ABSTRACT

Objectives: Computed Tomography (CT) scan parameters such as slice thickness have a direct impact on any 3D models derived from the volumetric data. Higher slice thickness spacing leads to loss of resolution quality in the visualizations.
Materials and methods: Twenty CT head scans were acquired at a 0.625 mm slice thickness. These data sets were resliced a range of 1–5 mm slice thicknesses. The resultant 3D models of the skull were compared using the 0.625 mm model as a standard. Differences in surface area, volume and part-to-part comparison were analyzed.
Results and conclusions: There were significant differences in surface area, volume and part-to-part comparison analyses from the 0.625 mm skulls as determined with One-way ANOVA by a *p*-value less than 0.05. Part-to-part comparison proved to have the greatest sensitivity for detecting geometric differences between slice thickness treatments. This study proposes using a 1.25 mm maximum slice thickness when forensic practitioners require 3D reconstruction in their casework.

1. Introduction

Forensic practitioners such as forensic pathologists, radiologists and anthropologists are regularly tasked with identifying unknown human remains and determining cause of death in known and unknown individuals. Medical imaging has played a more prominent role in those efforts in recent years, especially with the use of post-mortem Computed Tomography (PMCT) [1,2]. In the course of casework, three-dimensional (3D) models of anatomical structures are made to aid in different parts of the forensic analysis. Fueled by advances in various disciplines like computer science and biomedical engineering, 3D model detail and complexity has exponentially increased in recent years. However, clinical imaging standard slice thicknesses have often restricted the resolution that can be reconstructed, thus limiting the level of detail. This loss of feature distinction can result in potential misidentifications as well as the loss of trauma or pathology visualization.

With a growing forensic imaging field, the establishment of minimum standards regarding data capture and 3D reconstruction need to be addressed [3,4] to meet expectations of forensic investigations and the subsequent legal processes. One of the benefits of digital data is the long-term storage of digital evidence but there is a balance of storage space with the capture of these larger datasets [5,6]. With medical scanning, smaller slice thicknesses are associated with larger datasets. The two settings that have the greatest effect on 3D model quality are slice thickness and field of view (FOV). Slice thickness in CT scans normally ranges from submillimeter to 5 mm or above depending on the anatomy being imaged. FOV varies depending on the overall width of the specimen being scanned. As FOV is subject specific, the setting that scanner operators or radiological technologists have the most control over is slice thickness. Other studies have examined the role scan parameters have on 3D modeling but they have been limited in scale and scope by examining mandibles, hyoids and fibula [7–9]. More complicated geometries, such as the human cranium, can cause great difficulty with balancing slice thickness and resolution for visualization of the fine anatomical features.

The purpose of this study was to examine a complex biological geometry, namely the human skull, and examine what effect slice thickness had on the 3D reconstruction of the anatomical features. Surface area, volume and part-to-part comparison, which have

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been used in various engineering and manufacturing fields [10–13], were utilized to quantify the differences between treatments. Since acceptance of visualization is dependent on the perceived level of resolution, this study attempted to determine the maximum CT slice thickness for image data capture that maintains anatomic fidelity, or exactness of detail, in the resultant 3D model [14]. This information will help forensic practitioners with setting medical imaging protocols in their future casework when 3D reconstruction is desired.

2. Materials and methods

Twenty head CTs from living patients were collected from our anonymized research database. This data was collected under IRB approval for Human Subject Research following all ethical policies for patient data research. All scans were collected on a GE LightSpeed VCT 64 slice scanner at an initial 0.625 mm slice thickness. Scan FOV was relative to cranial size but on average was 242 ($\pm$19) mm. Ten specimens were female with an average age of 30 ($\pm$8) years. Ten specimens were male with an average age of 39.6 ($\pm$7) years. Skulls with excessive flaring artifacts from fillings or metal implants were excluded from the sample.

The DICOM files were imported into the software package *Mimics 18.0* (Materialise). The initial file created from the 0.625 mm scan was then resliced to 1 mm, 1.25 mm, 2 mm, 2.5 mm and 5 mm for each head. The FOV and pixel size remained consistent through this process. The resliced feature preserved the initial Cartesian coordinates original to the scan, making future registration unnecessary. The osseous material was isolated using the threshold value of 226–3071 Hounsfield units. The same threshold values were used for the study's duration to avoid any subjectivity in what constituted osseous material. The 3D model was then created via tessellation. An example of each slice thickness treatment can be seen in Fig. 1.

Each model was then exported as a stereolithographic file (STL) for further analysis. This process was repeated so there was a corresponding 3D model for each skull created from the 0.625 mm, 1 mm, 1.25 mm, 2 mm, 2.5 mm and 5 mm slice thicknesses. Initially 37 linear measurements were also captured. However, all of these measurements were landmark based. Attempts to place landmarks proved difficult with models created with 2 mm slice-thickness or greater due to the lack of detail or even boney surface. Sutures, boney process tips, tooth borders, and thin walls were either obliterated or indiscernible when it came to identifying landmarks. Each skull was then imported into *3-Matic 10.0* (Materialise) for data analysis.

Part-to-part comparison analysis is a tool commonly used to objectively test manufactured parts. Examples of usage include automobile parts, airplane parts to simple bottle cap to bottle comparison tests. Production parts are compared against a "gold standard" to insure accuracy and usability [10]. The original part is scanned via a 3D capture device, such as 3D laser scanner or CT, and compared against another produced part. The tolerance of the test is dependent on the scanner used to capture the data. The two objects are registered against one another and directly compared. A threshold can be set constraining how much difference is allowed in the analysis while still being considered "identical". The limitation to the level of detail comparable is limited by the scan resolution. Machined parts often have clean geometric edges and shapes, which allow for more stringent thresholds of comparison [10–13]. In this study, a part comparison analysis was conducted for each version of the skull using the 0.625 mm skull as a template. Since organic shapes, especially complex biological shapes like a skull lack the crisp geometry, we limited our threshold to $\pm$0.5 mm. Furthermore, each 3D model surface area and volume

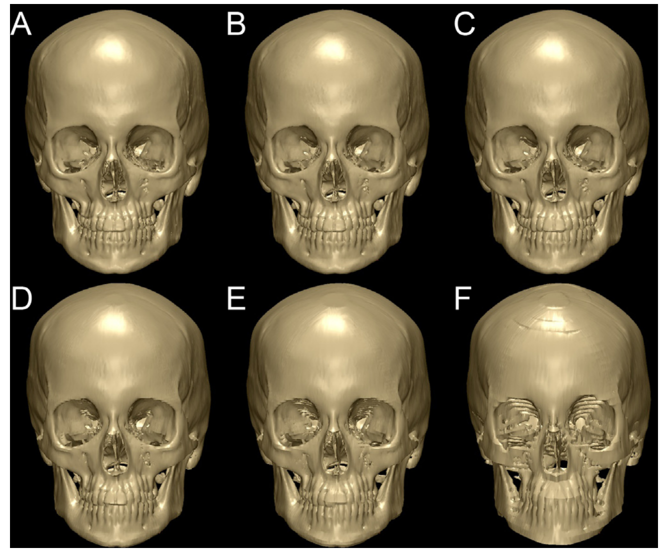

Fig. 1. Representative 3D model using slice thicknesses of (A) 0.625 mm, (B) 1 mm, (C) 1.25 mm, (D) 2 mm, (E) 2.5 mm and (F) 5 mm.

were recorded and compared against the 0.625 mm derived skull. An example of a part-to-part comparison can be seen in Fig. 2.

One-way ANOVAs were run for the surface area, volume and part comparison analysis results. The surface area and volume measurements were normalized against the 0.625 mm values. A Tukey Post-Hoc test was run for cases where the ANOVA was significant. Paired *T*-tests were also run examining what, if any, influence sex had as well. Significance was determined by a *p*-value less than 0.05.

3. Results

The one-way ANOVA comparing surface area over the 1 mm, 1.25 mm, 2 mm, 2.5 mm and 5 mm treatments was statistically significant ($F(4,95)=4.254$, $p=0.003$). A Tukey post-hoc test revealed that there was a statistical difference between the 1 mm (0.95 ± 0.01) and the 5 mm (0.84 ± 0.09, $p=0.001$) surface area ratio. However, there were no significant differences between the 1 mm, 1.25 mm, 2 mm and 2.5 mm groups ($p=0.359$, 0.695, 0.322).

The one-way ANOVA comparing volume over the 1 mm, 1.25 mm, 2 mm, 2.5 mm and 5 mm treatments was also statistically significant ($F(4,95)=79.966$, $p<0.001$). The Tukey post-hoc test for volume revealed that there was a statistical difference between the 1 mm (0.95 ± 0.01) and the 2.5 mm (1.00 ± 0.01, $p=0.001$) and 5 mm (0.97 ± 0.02, $p<0.001$) volume ratio. However, there were no significant differences between the 1 mm, 1.25 mm, and 2 mm groups ($p=0.977$, 0.506).

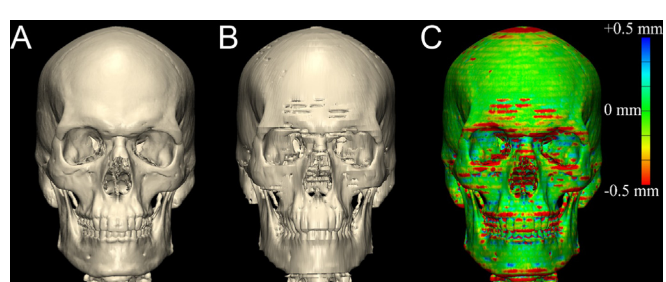

Fig. 2. Representative part-to-part comparison analysis with (A) 0.625 mm model, (B) 5 mm model and (C) analysis results.