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# Volumetric Evaluation of 3D Models Generated by Different Surface Treatment Protocols

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***ABSTRACT***

**The objective of this study was to compare the volume of three-dimensional (3D) models generated by different scanners and computational modeling protocols. Eight dry mandibles were scanned by five different computed tomography (CT) scanners and by a 3D-scanner. Three-dimensional models were generated, received different surface treatment processes, and the final volume of the 3D models was compared. The results show that there was no significant difference among the volume of the 3D models generated by the different CT scanners and surface treatment techniques, however, the model volume generated by the 3D-scanner show the highest volume. It can be concluded that the different combinations of surface treatment protocols did not determine differences in the model volume generated by different CT and CBCT scanners and that the 3D-scanner determined the highest volume models.**

**Keywords:** Computer software, cone beam computed tomography, engineering, helical computed tomography, imaging, software, three dimensional.

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## I. Introduction

Reverse engineering is defined as a process of obtaining digital models from the scanning or digitizing of finished products [1]. In the health field, the finished product is a segment of human anatomy, and to perform this process, we can use imaging devices such as computed tomography (CT) or, more recently, three-dimensional (3D) scanners. In CT scanner, the data captured includes the surface and internal tissues of the selected segment. In 3D-scanners only the surface information of that anatomical area is acquired.

After capturing the information of the selected anatomical segment, different electronic tools in different software can be used to generate 3D images. This process is understood as computational modeling. These tools include techniques of segmentation and surface treatment, such as smoothing and refinement [2]. The smoothing command has the function of eliminating the surface vertices and edges giving the solid a smoother appearance, and it can be used continuously to obtain an ever less faceted model. The refinement command improves the resolution of the model by increasing the number of triangles that make up the image. The refinement divides each triangle into four smaller triangles, improving image quality [3]. These phases are essential to ensure an adequate image of the anatomical segment.

These processes generate a large amount of data and require large storage spaces. Thus, it is important to establish protocols capable of obtaining reliable data without compromising the storage space. The objective of this study is to compare the volume of 3D models obtained by different reverse engineering devices and computational modeling techniques.

## II. Methods

This research was approved by the Research Ethics Committee of the Dental School of the Federal University of Bahia (Salvador, Bahia, Brazil). Eight dry human mandibles were randomly selected from the anatomy laboratory of the Dental School. The anatomical integrity of the mandible and the absence of metal fill were the inclusion criteria. Each mandible was scanned by five different CT scanners: CT Twin Flash® (Elscint, Haifa, Israel); Somaton Spirit® (Siemens, Erlangen, Germany); Asteion S4® (Toshiba Medical System, Japan); Optima CT660® (GE Healthcare, Wisconsin, USA); and i-CAT® (Imaging Sciences International Incorporation, Hatfield, Pennsylvania, USA). An overview of all scanners and settings is provided in Table I. The images were exported as DICOM (Digital Imaging and Communication in Medicine) files and processed in 3D Doctor® software (Able Software Corp., Lexington, Massachusetts, USA) for the generation of 3D models. The models received superficial treatment, being divided into four groups: without superficial treatment; only smoothed; only refined; smoothed and refined (Fig. 1). The resulting 3D models were exported and stored in STL (Standard Triangle Language) files.

TABLE I: OVERVIEW OF THE CT SCANNERS

| Manufacturer | Model | NOC | Inc. (mm) | ST (mm) | FOV (cm) | RA |
|---|---|---|---|---|---|---|
| Elscint | CT Twin Flash® | 2 | 1 | 1.1 | 25 | Bone |
| Siemens | Somaton Spirit® | 2 | 0.5 | 1 | 25 | Bone |
| Toshiba | Asteion S4® | 4 | 0.3 | 0.5 | 25 | Bone |
| GE | Optima CT660® | 128 | 5.625 | 0.625 | 25 | Bone |
| Imaging Sciences | i-CAT® | -- | -- | 0.4* | 8 | --- |

*isometric voxel; NOC= number of channels; Inc.= increment; ST= slice thickness; RA= reconstruction algorithm; FOV= field of view.

TABLE II: MEAN OF THE VOLUME OF THE 3D MODELS GENERATED BY DIFFERENT SURFACE TREATMENT PROTOCOLS, ACCORDING TO CT SCANNER

| | No treatment | Only refinement | Only smooth | Refinement and smooth | p-value |
|---|---|---|---|---|---|
| Dual-CT 1 | 40548.10 | 40414.76 | 39933.12 | 39788.39 | >0.05 |
| Dual-CT 2 | 29949.23 | 29938.85 | 29909.05 | 29899.11 | >0.05 |
| MDCT-4 | 36796.89 | 36794.17 | 36785.04 | 36781.28 | >0.05 |
| MDCT-128 | 28108.30 | 28087.55 | 28038.15 | 28023.57 | >0.05 |
| CBCT | 31760.01 | 31801.76 | 31903.97 | 29818.18 | >0.05 |

TABLE III: MEAN OF VOLUME OF THE 3D MODELS, ACCORDING TO CT AND 3D-SCANNER AND SURFACE TREATMENT PROTOCOL

| | No treatment | Only refinement | Only smooth | Refinement and smooth |
|---|---|---|---|---|
| Dual-CT 1 | 40548.10[a] | 40414.76[a] | 39933.12[a] | 39788.39[a] |
| Dual-CT 2 | 29949.23[b] | 29938.85[b] | 29909.05[b] | 29899.11[b] |
| MDCT-4 | 36796.89[a] | 36794.17[a] | 36785.04[a] | 36781.28[a] |
| MDCT-128 | 28108.30[b] | 28087.55[b] | 28038.15[b] | 28023.57[b] |
| CBCT | 31760.01[a] | 31801.76[a] | 31903.97[a] | 29818.18[b] |
| 3D-scanner | 41745.82[a] | 41745.82[a] | 41745.82[a] | 41745.82[a] |

In columns, different letters indicate significant differences.

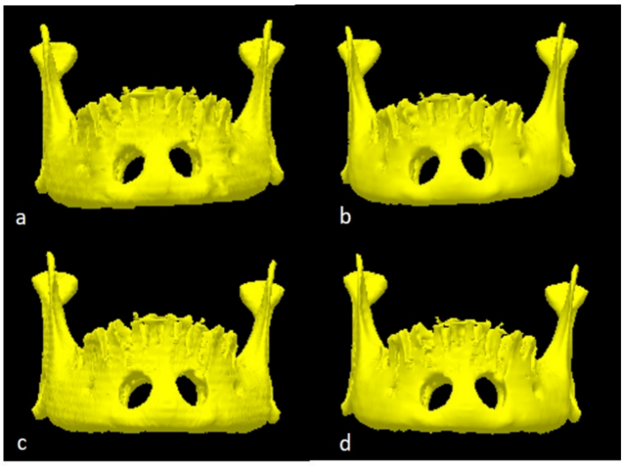


Fig. 1. Models with different surface treatment protocols. No treatment (a); only smooth (b); only refinement (c); refinement and smooth (d).

Each jaw was also scanned by the Scanflex-API/BACES® (Automated Precision Inc, Maryland, USA), mounted on the Baces3D® base, to a precision of 0.01 mm. Using the Geomagic Studio® software, a point cloud file was initially generated, which was then converted into a triangle mesh (STL file) and saved.

The volume of each 3D model was calculated (in cubic voxels) at the 3D Doctor® software, by a single examiner, twice, with an interval of one week between evaluations. In cases where the two measures differed from each other, a third assessment was carried out.

For the data analysis, the Shapiro-Wilk test was used to test adherence to normality, with parametric tests being adopted. The volume measurements of the solids obtained for each CT scanner and the protocols of surface treatment were compared by ANOVA and Tukey post hoc test. The comparison between CT scanners and 3D-scanner was performed by ANOVA and Dunnett post hoc test. The significance level of 5% was adopted for the analysis.

## III. RESULTS

We obtained 160 models from CT scans and eight models from 3D-scanner. The results show that there is no volumetric difference among 3D models submitted to different surface treatment protocols (Table II).

Comparing the models obtained from the CT scanners with the models from the 3D-scanner, the results show a significant difference between a dual-CT scanner and the MDCT-128 and the 3D-scanner, when the model was submitted to none or only one superficial treatment. When the model was submitted to refinement and smooth tools simultaneously, the 3D-scanner also differed from CBCT (Table III).

## IV. DISCUSSION

Although widely used, the implications of computational modeling techniques on virtual models, especially the surface treatment protocols, are little discussed in the literature. Each tool has specific functions that by different algorithms modify the image appearance and size/volume. How much this dimensionally modifies such models is still uncertain. In this study, two types of surface treatment were evaluated: the smooth tool that eliminates edges and superficial vertices; and the refinement tool that improves quality and image resolution [3]. The results showed that the different surface treatment protocols did not determine volumetric differences in models obtained from different CT scanners.

Reference [4] demonstrated that the use of only one surface treatment tool did not modify the dimensions of the 3D models, while the simultaneous use of two tools increased the differences between the 3D model and the dry mandible. To obtain the best results, according to the authors, only one of the processing tools should be used. This differs from the present study.

In the present study, when the volume of 3D models obtained from 3D-scanners was compared to the volume of models obtained by CT scanners, regardless of the surface treatment protocol, it can be observed that the models of the 3D-scanners presented a statistically larger volume than those dual-CT (Somaton Spirit®) and MDCT-128. When two surface treatment protocols were applied, the models from CBCT also presented statistically different volumes.

Considering that the images of the 3D-scanners were augmented, this seems to indicate that better CT spatial resolutions, as well as a larger number of channels in the MDCT scanner favor the obtaining of more faithful solids. The MDCT scanners have X-ray detector array design which allows for multiple slices during gantry rotation. This design allows for faster scanning and acquisition of thinner slice widths and allows for two and 3D reconstructions with similar resolution as the source images [5]. For MDCT scanner, the image quality does not depend on the slice thickness or the increment, but on the high signal-to-noise ratio characteristic of this image method [6]. The CBCT images are generated with submillimeter isometric voxels. This allows a high image quality. This agrees with some studies that have already demonstrated the superiority of images that have better spatial resolution [7]-[9].

Considering that 3D-scanners have surface capture failures [10], especially in curve area [11], it can be inferred that the 3D-scanner, in the present study, tended to increase the volume of the solids, making them dimensionally incorrect. The present study agrees with the study by [10] in which, although the measurements of 3D-scanners presented a great correlation with the measurements obtained by the conventional techniques, these were volumetrically larger. For these authors, the source of these errors may be the difficulty of finding landmarks during capture. Instead, in the study by [12], the measurements of scanned models were significantly lower when compared to the values obtained in the conventional models. For these authors, the models obtained through 3D-scanners may present distortions and low precision when compared to conventional models. Devices with a high index of accuracy is usually limited to small areas such as single teeth or quadrants of an arch. Reference [11] argue that the structural sensor of 3D-scanners does not have software or hardware capable of defining areas of high complexity as large curvatures but are effective in reproducing the facial general forms.

## V. Conclusion

We can conclude that the reverse engineering devices tested, and the refinement and smoothing tools applied in computer modeling do not interfere with the volume of 3D models.

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## Conflict of Interest

Authors declare that they do not have any conflict of interest.

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