

New Virtual Tool for Accurate Evaluation of Facial Volume

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Abstract

Objective: The aim of this study is to develop a protocol to accurately measure facial volume through three-dimensional (3D) technology and virtual tools using free software.

Methods: Eighteen cadaveric hemifaces were evaluated. A tissue expander was inserted in the anterior maxilla region and 3D digital meshes of a face side were captured by a scanner at 4 stages of controlled injection of saline solution into the expander (0, 3, 6, and 10 mL). Four virtual models of every face side were aligned in relation to the reference model (0 mL). A virtual cube (343 cm³) was added to the scene overlapping the aligned meshes. Volume difference from the virtual cube external section related to the mesh surface was calculated.

Results: Strong correlation between measured virtual volume and real expanded volume was observed (r , 0.997-0.999; $P < 0.001$). Significance difference of virtually measured expanded hemifacial volume with and without expander was verified ($P < 0.001$).

Conclusions: Protocol using 3D technology and virtual tools with Blender free software enabled precise calculation of volumetric facial variation in cadavers.

Keywords: three-dimensional image; face; plastic surgery; computer-aided image processing; photogrammetry; software.

1. Introduction

The use of 3-dimensional (3D) imaging and a 3D digitized mesh in plastic surgery enables the acquisition of objective data and facilitates pre- and postoperative evaluation of malformations, sequelae of trauma and tumors, and orthognathic surgery. In addition, the 3D mesh facilitates guide production with virtual planning and 3D printing[1]–[6], quantification of results after aesthetic surgery[7]–[9], and simulation of volume changes[10]–[16]. Furthermore, digital files may be transmitted easily, enabling file exchange for remote evaluation and wider potential for the clinical use of the 3D mesh[17].

Anthropometric measurements of 3D mesh are obtained from data extracted using varied specialized proprietary software programs that are integrated into image capturing devices. The native software may calculate linear, angular, area, and volume dimensions and perform comparative studies. The user may be compelled to purchase native software that is bundled with the device to enable extraction of metric information from coordinate data[18]–[20]. The high cost of devices may limit the large-scale use of this technology[21]–[23]. Furthermore, all metric-bound studies become inaccessible to potential users who cannot purchase the device. This factor may prevent worldwide exchange of experience, information sharing, and method consolidation.

Currently, 3D digital meshes are not exclusively provided by scanners. Stereo photogrammetry used with conventional photography enables the creation of meshes with several acceptable polygons, and mesh capturing with this method may enable accurate extraction of information. In addition, new tools and scanners are available that may capture meshes (Structure Sensor, Occipital Inc., San Francisco, CA, USA; Kinect, Microsoft, Redmond, WA, USA)[24].

A free software program is available and being used in medicine to evaluate 3D data (Blender, Blender Foundation, Amsterdam, Netherlands)[19], [20], [25]–[28]. This software enables the user to capture and import meshes files with varied sources and formats. Although this software is accessible to physicians who are familiar with digital technology, and may reduce process costs, limited information is available about the use of this software in planning reconstructive procedures for facial asymmetry.

The purpose of the present study was to develop and validate a protocol for facial volume calculation using 3D technology and free software.

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2. Method

Specimens and procedures

We obtained 9 cadavers (5 males, 4 females; age, 18-78 y) from the Death Verification Service of São Paulo City at the University of São Paulo. Other specimens were excluded because of the presence of a facial beard or scars. The study was evaluated and approved by the Research Ethics Committee of the University of São Paulo Medical School (research protocol number 001/15).

The cadavers were placed on a dissection table in the horizontal dorsal decubitus position, and the face was isolated and exposed with surgical drapes. A study number was assigned to each cadaver. Colored pins were applied to cephalometric landmarks including the glabella, nasion, mentum, and external and internal ocular canthal ligaments; these landmarks were used to align the digital meshes. Through a 2-cm intraoral incision at the superior gengivolabial sulcus a 4 × 3-cm supraposterior premaxillary space was made with blunt dissection, and an empty 16-mL rectangular tissue expander (Silimed, Rio de Janeiro, Brazil) was introduced into the middle-third of the face, positioning the exterior valve of the catheter of the expander through the labial commissure. A 3D mesh was captured with a structured light surface scanner (Artec 3D MHT, Artec 3D, Luxembourg) that was held at 70 cm from the face and connected to a laptop computer (Precision M 4700, Dell, Round Rock, Texas, USA) with a Universal Serial Bus cable; the scanner was moved from the side of the face in 180-degree surrounding to the contralateral side of the face. Subsequently, saline solution was injected into the tissue expander through a remote valve in 3 steps to complete the cumulative injection of 3, 6, and 10 mL, and another digital mesh were captured with the scanner after completion of each step of saline injection (total, 4 digital meshes: 0, 3, 6, and 10 mL) (Figure 1,2). The tissue expander was deflated, and the procedure was repeated on the contralateral side of the face.

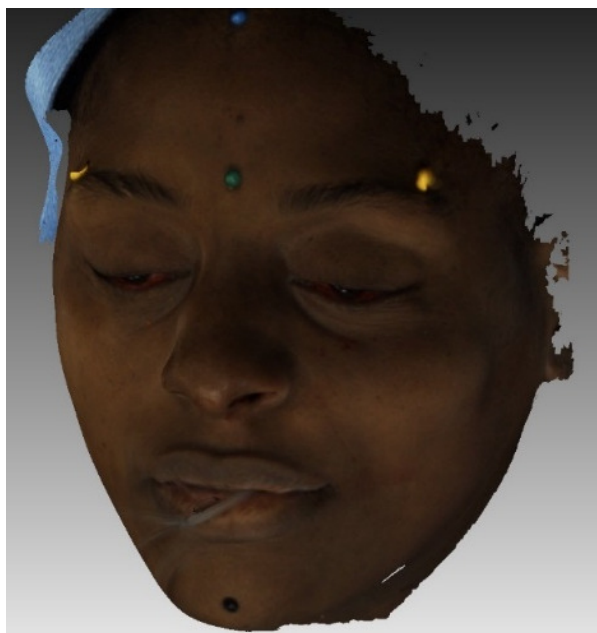


Figure 1. Left oblique view of 3D digital mesh from cadaveric face obtained using 3D surface scanner with skin texture adjustment after tissue expander was inserted into the left maxillary region. Colored pins and insufflation catheter through oral commissure are shown. Tissue expander volume: 0 mL.

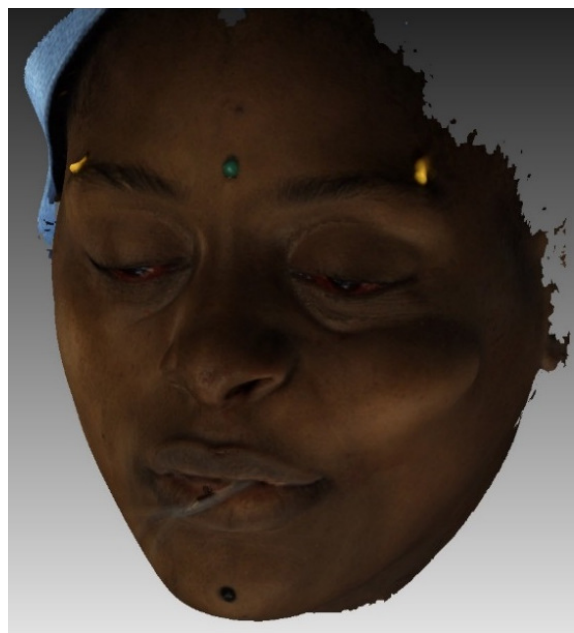


Figure 2. Left oblique view of 3D mesh from cadaveric face obtained using 3D surface scanner with skin texture adjustment after tissue expander inserted into the left maxillary region. Colored pins and insufflation catheter through oral commissure are shown. Tissue expander volume: 10 mL.

All captured scanned images were reconstructed with software that was native to the scanner (Artec Studio 9, Artec 3D). The images were softened after global realignment of the cloud of data points. The resulting 3D meshes were saved as STereoLithography (STL) files.

A script was written in a programming language (Python, Python Software Foundation, Wilmington, Delaware, USA; CTI Renato Archer Information Technology Center in Campinas, São Paulo, Brazil) to enable STL files to be imported into the 3D data software (Blender, v2.76, Blender Foundation) and to separate the meshes in different layers. After STL importation a metric unit system was adjusted in scene with a scale of 0.001 and Misc and 3D printing add-ons were activated. The script enabled the

creation of 2 cubes with known volume $7 \times 7 \times 7$ cm (total, 343 cm^3). Meshes were aligned against the reference mesh that was created with empty tissue expander volume, and the cubes were positioned manually to include the detachment area and tissue expander base, with 1 cube transfixing the expanded hemiface and the other cube symmetrically transfixing the contralateral hemiface as a control. By applying a Boolean modifier tool, each cube was submitted to a difference command relative to its mesh, creating a cut in the cube at its interface with the mesh. The volume of the external portion of each cut cube was calculated using the 3D printing command (Figure 3-5), and the delta (difference between an initial and final value) of the volume of each cube relative to the cube of the mesh with the empty expander was calculated. The Accurate Volumetric Index (AVI) was defined by the virtual volume difference between each measured external virtual cube volume minus the corresponding external cube volume from the reference mesh (AVI -1, measured > reference; AVI 0, no difference; AVI +1, measured < reference).

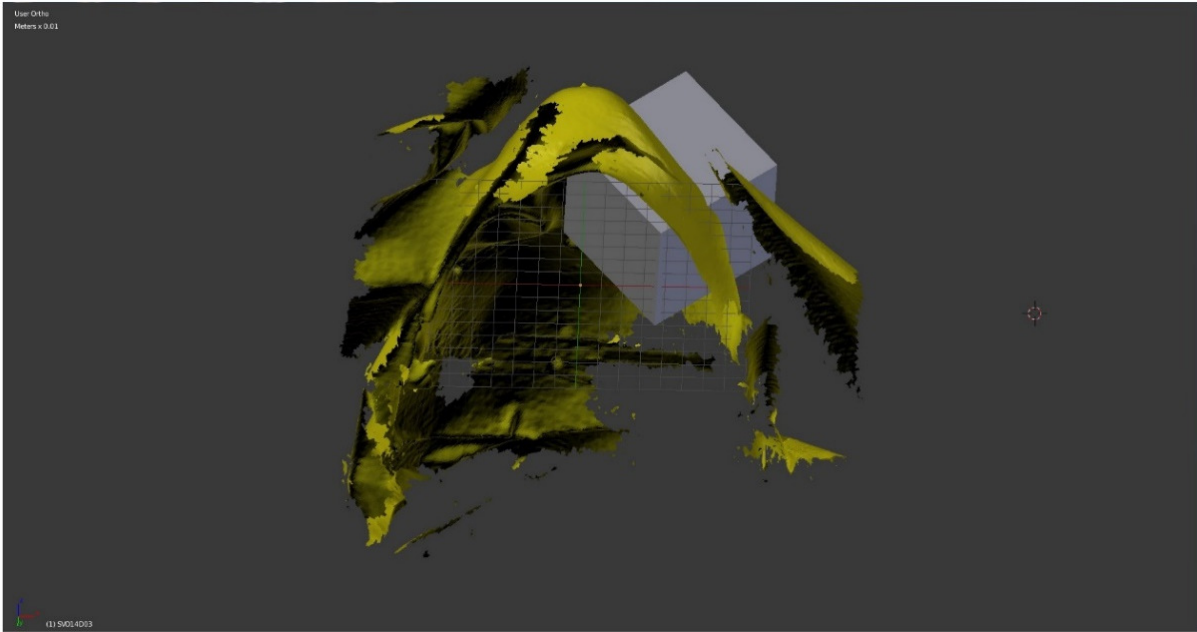


Figure 3. Inferior view of a virtual cube intersecting a facial mesh.

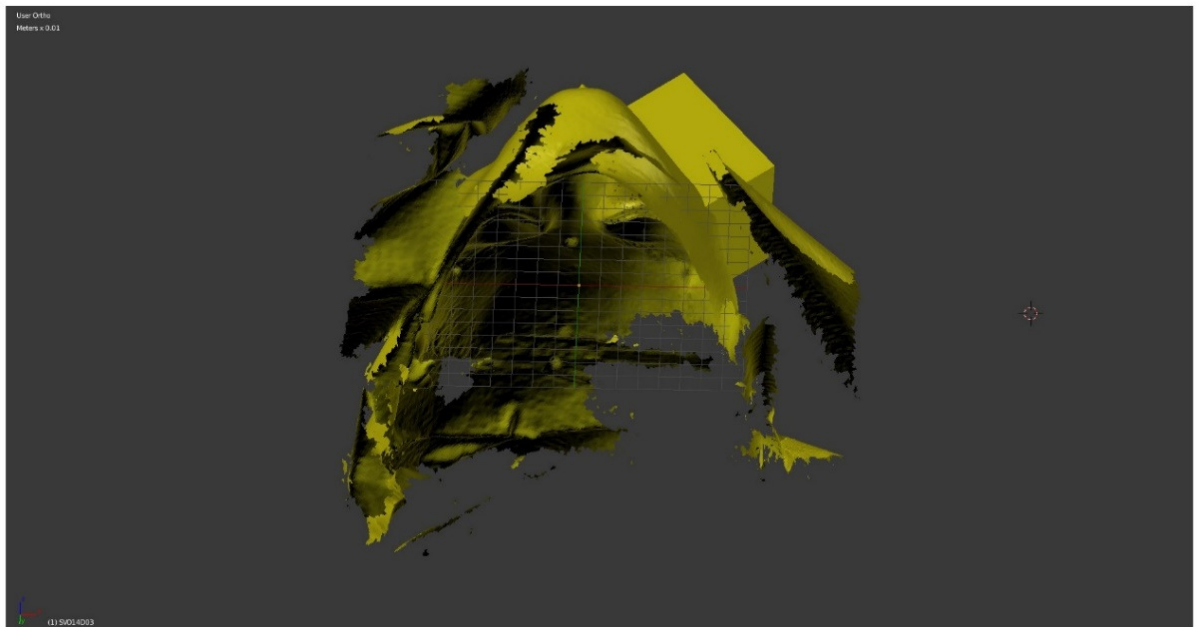


Figure 4. Inferior view of intersected virtual cube after subtraction by facial mesh surface.

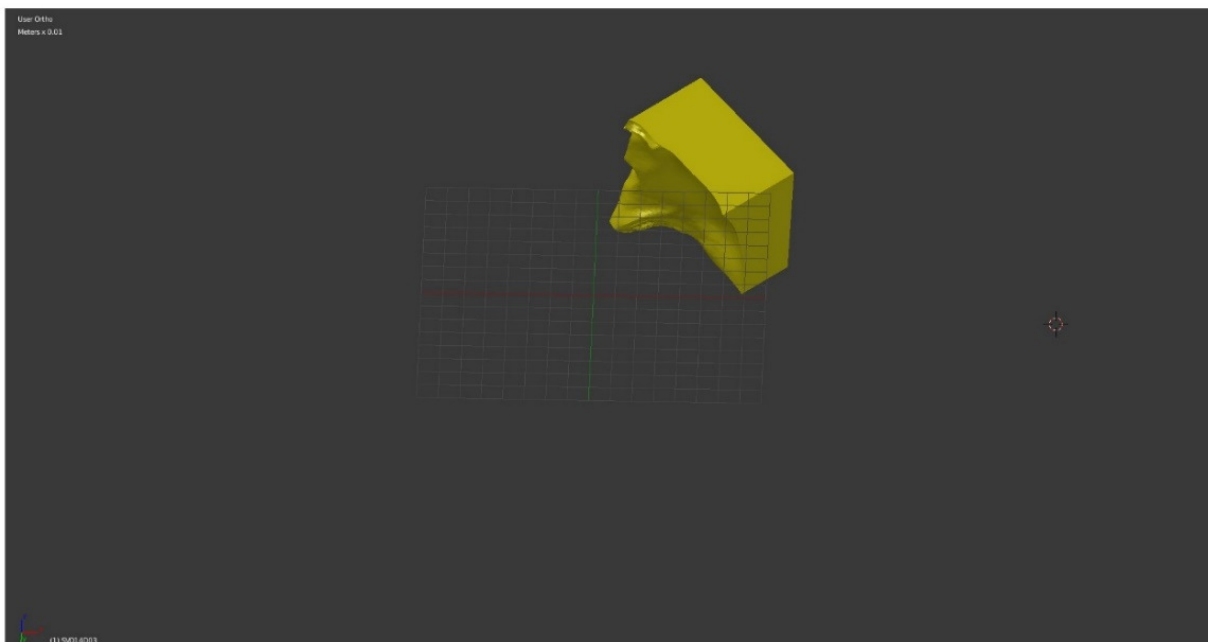


Figure 5. Virtual cube external section isolated after intersection and ready to proceed to the volumetric calculation phase.

3. Test/Data

Sample calculations suggested that the observed correlations would be > 0.80 . For tests with power at 80% and significance level at 5%, 9 samples would be required in the study.

All data were tabulated with a spreadsheet program (Excel, Microsoft, Redmond, Washington, USA). Data analysis was performed with statistical software (SPSS 17.0 for Windows). Quantitative variables were described by observing minimum and maximum values and calculating means, standard deviations, and quartiles. Data from the control and tissue expander sides were compared with nonparametric Wilcoxon signed rank test. Correlations were evaluated with Pearson product moment correlation. Statistical significance was defined by $P < .05$.

4. Results

The volume difference between cubes was taken into account. Volumetric measurement of the part of the virtual cubes external to the digital mesh showed variation between the maximum and minimum values for each measurement step with different tissue expander volume. A decrease in mean measurements between cubes measured from the meshes with tissue expander volume from 0 to 10 mL, and the standard deviation derived from minimum and maximum measurements with approximate values, were verified from measurements obtained.

Strong correlation was observed between all measurements (Table 1,2). Linear correlation plots showed a positive uniform linear increase in external virtual cube volume difference related a reference mesh with increased tissue expander volume for the 18 hemifaces studied (Figure 10). Control measurements were obtained consistently from the contralateral hemiface with no tissue expander. Significant differences were observed for both right and left sides between tissue expander and control groups between the volume measurement with empty tissue expander (0 mL) vs. the measurements with other tissue expander volumes; the control group had significantly lower range delta compared with the expander group ($P = .008$) (Table 3). In all cases, AVI was maintained at -1 on the control side and +1 on the expander side; no AVI = 0 values were observed.

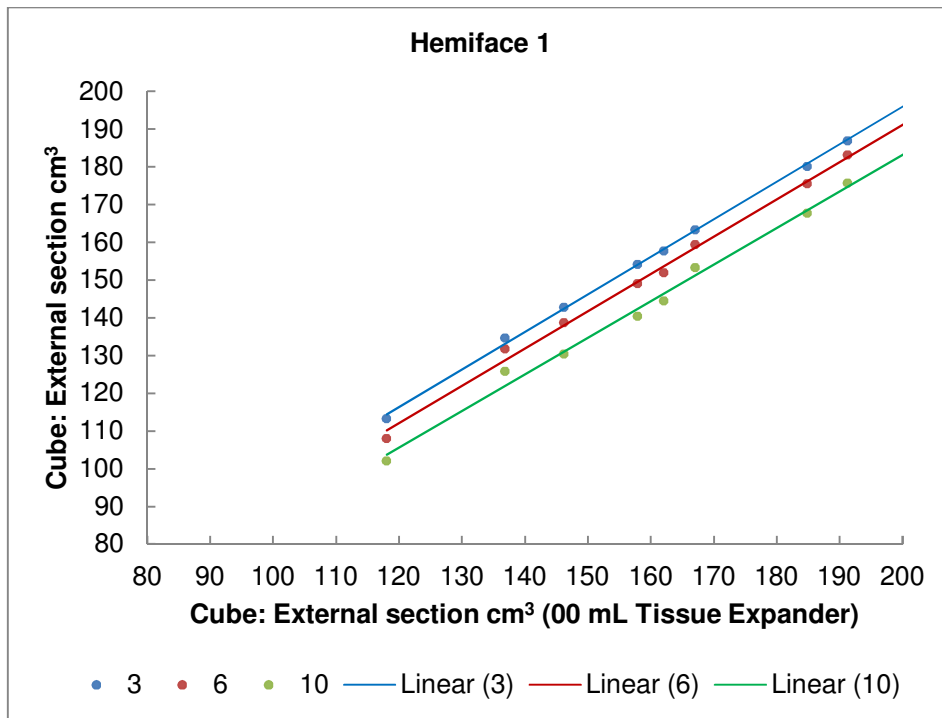


Table 1 – Correlation between measurements hemiface 1. Vertical column is external section of virtual cube in cm^3 , horizontal is external section of virtual cube in cm^3 blue line with expanded 3 mL, red line 6 mL and green line 10 mL.

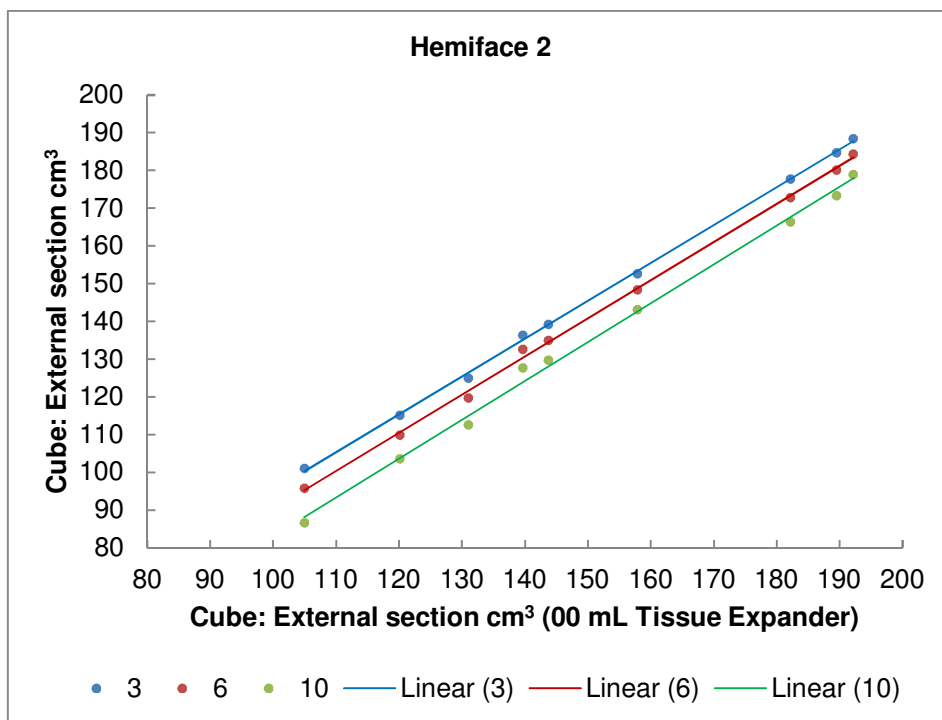


Table 2 – Correlation between measurements hemiface 1. Vertical column is external section of virtual cube in cm^3 , horizontal is external section of virtual cube in cm^3 blue line with expanded 3 mL, red line 6 mL and green line 10 mL.

Conclusions:

In summary, the present study showed that a surface scanner and 3D digital meshes enabled the calculation of complex, organic meshes with free software for facial volumetric evaluation in cadavers. The method was effective in showing local volume variation, cost effective because of the free software, and enabled rapid data acquisition. Further studies and training programs are needed for colleagues to exchange information, develop indications, and increase availability of this method in plastic and reconstructive surgery.

The limitations of the present study can be considered as technical knowledge regarding familiarization with three-dimensional technology, concepts and applications. From the capture of the meshes, export of the files and use of the tools of the software. The availability of equipment for capturing the meshes, the scanners, also restricts the use, but the growing offer of free software to create 3D models with photogrammetry is promising.

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