Original Article

The use of a three-dimensional mesh in plastic surgery

Uso de malhas tridimensionais em cirurgia plástica

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■ **ABSTRACT**

Introduction: Image recording as we know it today has evolved considerably from the beginning of photography by means of light printing directly onto a photosensitive material, up to the mathematical algorithms that constitute three-dimensional (3-D) meshes in stereophotogrammetry. The 3-D technology to capture and extract reliable information in plastic surgery has evolved considerably in recent years. However, the procedure for which the applicability potential can be exploited directly by the surgeon in their routine work should be fully understood. The objective of this work was to address the conceptual aspects and the accuracy of the image capture, and to illustrate clinical applications of 3-D meshes, with emphasis on their importance in clinical use. **Methods:** Literature on the principles of image capture and formation of tridimensional models was reviewed, as well as the description of the application of the tests of accuracy with the use of a structured-light scanner. Clinical indications of 3-D meshes were evaluated both in the preoperative planning and postsurgical follow-up. **Results:** The principles of the image capture technologies were established, and the reproducibility of the validation of the tool to capture meshes was confirmed. The clinical applicability both in programming and monitoring was exemplified. **Conclusion:** The conceptual difference between photography and the 3-D mesh system was established, together with the introduction of the principles of 3-D technology. The clinical applications of the method were presented, evidencing the promising application of dimensional models in plastic surgery.

Keywords: Reconstructive surgical procedures; Three-dimensional image; Photogrammetry; Anthropometry; Measures; Methods and theories.

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■ **RESUMO**

Introdução: O registro da imagem como conhecemos hoje evoluiu muito desde os primórdios da fotografia por meio da impressão da luz diretamente em um material fotossensível, até os algoritmos matemáticos que constituem malhas tridimensionais, na estereofotogrametria. A tecnologia 3D para captura e extração de informações confiáveis na Cirurgia Plástica tem evoluído muito nos últimos anos; contudo, há necessidade de compreensão do método para que o potencial de aplicabilidade possa ser explorado diretamente pelo cirurgião na sua rotina. O objetivo deste trabalho é abordar os aspectos conceituais, a acurácia da captação e ilustrar aplicações clínicas das malhas tridimensionais, salientando a importância na utilização clínica. **Método:** Foi feita uma revisão dos princípios de captação de imagens e da formação de modelos tridimensionais por meio da revisão da literatura, bem como uma descrição da aplicação de testes de acurácia com o uso de scanner de luz estruturada. Indicações clínicas das malhas tridimensionais foram avaliadas tanto no planejamento pré-operatório como no acompanhamento pós-cirúrgico. **Resultados:** Os princípios das tecnologias de captação da imagem foram estabelecidos e a reprodutibilidade da validação da ferramenta de captação das malhas foi confirmada. A aplicabilidade clínica tanto na programação, quanto no acompanhamento foi exemplificada. **Conclusão:** A diferença conceitual entre fotografia e malha tridimensional foi estabelecida, juntamente com a introdução dos princípios da tecnologia 3D. As aplicações clínicas do método foram apresentadas, evidenciando o uso promissor de modelos tridimensionais em Cirurgia Plástica.

Descritores: Procedimentos cirúrgicos reconstrutivos; Imagem tridimensional; Fotogrametria; Antropometria; Medidas; Métodos e teorias.

INTRODUCTION

Image recording as we know it today has evolved considerably since the beginning of photography by means of light printing directly onto a photosensitive material, up to the mathematical algorithms that make up three-dimensional (3-D) meshes. Much of the existing digital technology today was outlined from needs such as those that emerged after the placement of the *Hubble telescope* into orbit, in which an evolutionary technological leap in the capture and transmission of images occurred.

The same occurred with the migration of radiographic evaluation, which is a two-dimensional (2-D) image, to computed tomography with 3-D reconstruction, by which the accuracy of the analysis tool has impoved[1]. Three-dimensional imaging systems have been considered as an excellent alternative in the linear and angular measurement of the face[2-5] in comparison with 2-D imaging systems.

One must understand the conceptual differences between the formation of images of objects in two dimensions and that in three dimensions through principles of digital photography and the use of 3-D meshes. These meshes are obtained through stereophotogrammetry, which provides coordinates of the points of a 3-D object, estimated from data obtained by means of an instrument for recording images. An example of this is the flatbed scanner, which uses non-ionizing radiation and, regardless the technology used, enables computational processing, generating a computer file extension that can be easily stored, transported, and transmitted[4,6]. The analysis of data obtained from the mesh captured by the surgeon requires an initial understanding of the technology so that it can be used and information for each case can be extracted from it.

The use of 3-D meshes for preoperative assessment, planning, and monitoring has been validated as a tool in several areas of plastic surgery. The clinical applicability is in frank expansion, being incumbent on the surgeon to explore the possibilities.

OBJECTIVE

The objective of this work was to determine the conceptual aspects and the accuracy of the capture of the meshes through a structured light scanner, and to illustrate clinical applications of 3-D meshes.

METHODS

The research protocol (No. 001/15) was approved by the research ethics committee of the School of Medicine of the University of São Paulo.

By conceptual revision, differences between the photographic recording of an image and the capture of a 3-D mesh were established.

To review and confirm the accuracy of the measurement of 3-D meshes, the authors completed an initial comparative study based on the literature[7,8]. A coordinate measuring machine (CMM; Axiom too, USICAM Indústria e Comércio Ltda.), which is considered as the gold standard of measurement, was used. The coordinates of the mesh were obtained from a mannequin head made of a plastic material, fixed in a metal base, by using a structured light scanner (Artec 3D MHT). All the images captured by the Artec 3D scanner were reconstructed by using the Artec Studio 9 software of the scanner. After the global alignment of the point cloud, smoothing of the image was performed. The file of the mesh in .stl ("STereoLithography") format was then saved and exported to the software of the CMM.

To evaluate accuracy, a MAX silicone mannequin head (a realistic simulator for maxillofacial surgeries, created by the ProDelphus team) was used to obtain direct anthropometric measures with a pachymeter, having linear measurements between points taken and repeated virtually with the 3-D mesh[9].

The clinical applications presented were collected from the available bibliography and pilot cases gathered by the authors.

RESULTS

The authors used the available and free Internet sources of information to establish conceptual principles. Two bibliographical sources were chosen to establish the principles of digital photography; and three, for the technology of tridimensional models in order to characterize the peculiarities of each technology.

Method validation

The calculations performed for a comparative study between the coordinates obtained by a CMM and those of the mesh captured by the scanner generated a report of the tests, in which a maximum error of 0.4 mm was evidenced in some axis with few coordinates (Figure 1).

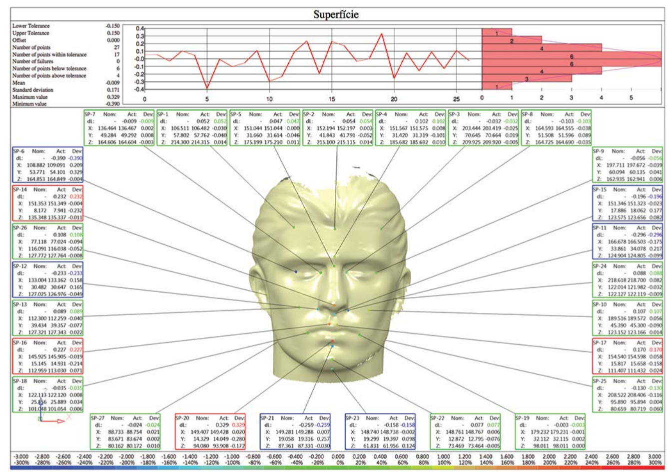

Figure 1. Comparative study of the coordinates measured in 27 points in a plastic mannequin head by using a scanner and a CMM, where the minimum and minimum deviations were 0.39 and 0.32, respectively.

In the comparison between the average of three direct linear anthropometric measurements from MAX, performed by using a pachymeter, with the mean of three measurements calculated through the software of the scanner, a difference of 1–1.5 mm[10] was observed (Figure 2).

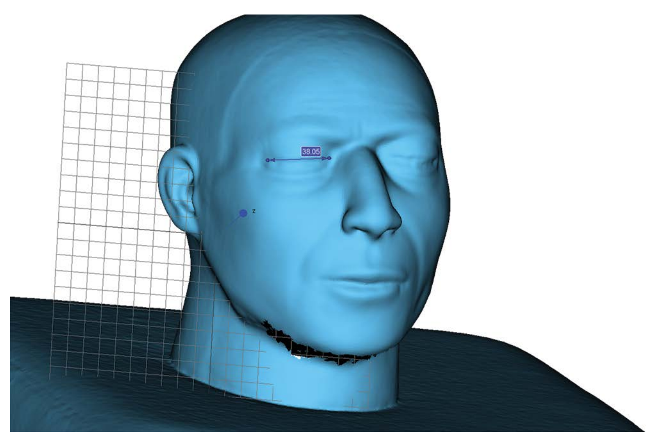

Figure 2. Three-dimensional MAX mesh captured with a structured light scanner, with linear intercanthal measurement of the right orbit of 38.05 mm, measured using the linear measurement tool of the software.

DISCUSSION

Digital Photography

The graphical representation of an image presents two dimensions, namely length and width. With this, the perspective, lighting, depth, and other aspects that characterize a flat picture are limited. In the photographic image, light converges to a focal point of the camera lens, which corresponds to the point of view of a monocular vision.

The digital camera resembles 35-mm film cameras, having lens, an opening, and a shutter. The difference is in the manner of capturing the image; instead of film, the digital camera has sensors (charge-coupled devices) with photosensitive devices that capture the stimulus of light on a single pixel, accumulating an electrical charge, with a higher or lower charge according to light intensity. With the closing of the shutter, this charge is transformed into a digital number[11].

Pixel is the smallest point that forms a digital image. It is the agglutination of picture and element, being that *pix* is the abbreviation in English for pictures. When in a monitor, each pixel is composed of three possibilities of filter (red, green, and blue), with capacity of 256 different shades. The proximity of one set of eight pixels with different filters (8-bit), by means of interpolation, determines the color that will be displayed. The more pixels that are used on an image, the more it approaches the original object. The term megapixel assigns a value of one million pixels, and the digital cameras determine the degree of resolution or image definition[12].

The image resolution is related with the size and, consequently, with the number of pixels. To enable storage and handling, a group called the Joint Photographic Experts Group (JPEG) established a file format that compresses the images. Thus, the file size is directly related to the resolution. The lowest resolution will entail a lower quality.

Tridimensional Models

Since 1435, when Alberti published De Pictura[13], which is one of the oldest works on linear perspective, mathematics is definitely related to the rules of the dimensionality of arts and images. However, only in 1975 did Reggini[14] expose a possibility of a computational means to correct the discrepancies in size that the linear perspective imposes, observed in a visual phenomenon called perceptual constancy, which is the tendency of the brain to interpret images from the retina. With this, 3-D computer graphics was born, along with works such as that by Kozbelt[15].

Unlike the information derived from 2-D images in pixels, a 3-D object is interpreted by the computer from data of the Cartesian coordinates, which are the linear intersection of two or more perpendicular planes. Each plane is called the axis, and each one is designated with a letter, X, Y, or Z, which denotes its direction. Thus, any point in space can be located and therefore its metric relationship with the other points.

Upon scanning an object, a "point cloud" is captured. A point cloud is nothing more than the junction of points measured in each axis, each one with X, Y, and Z coordinate values. By processing with a specific software, calculations are performed for "cleaning" the point cloud by setting a definitive coordinate for positioning in space, connecting each of them by a line called ridge. In general, at every three points, a flat surface called face is formed. At this time, the entire surface of the scanned object is represented by polygons called mesh, following the changes of the surface captured by the scanner. In the case of a structured light scanner, along with the capture of a point cloud, photos are created at intervals of time so that if prompted, the texture of the object can be added based on a "map" stored with the color information at each point.

The use of photography as an instrument of study for comparative assessment of the evolution of presurgery with postsurgery and surgical planning has been associated for a long time with the activities of plastic surgeons, especially in the area of craniomaxillofacial surgery. Initially, photos were generated from photographic films until the emergence of the current digital photos. Gradually, digital cameras have technologically improved. By means of the confluence with specific computer software, multiple linear and angular quantitative calculations could be made from photographs in two dimensions. Technological advances have provided the medical practice with evaluation methods that vary from stereophotogrammetry, image subtraction techniques, topography of Moiré, liquid crystal scanning, light scanning, and stereo lithography to video systems[4,16]. Together with their use in clinical evaluations, information technology introduced computer-aided surgeries[17].

As in the migration of a radiographic evaluation, which is a 2-D image, to computed tomography with 3-D reconstruction, the accuracy of the analysis tool has improved[1]. The 3-D imaging systems have been considered excellent alternatives in the linear and angular measurement of the face[2,4,5,18] in comparison with 2-D imaging systems.

Evaluation by using computed tomography and/or magnetic resonance imaging has disadvantages, as it may not record the external morphology with acceptable quality owing to the presence of "noise" that limit the information of soft structures, artifacts produced by patient motion, metal restorations, tissue compressions by support, time to perform, and exposure to ionizing radiation[2,17]. In addition, these examinations are costly.

The use of 3-D images is common in several fields of science such as geography, architecture, and auto parts industry. In medicine, as soon as the first studies began with the flatbed scanner, tests were made to assess the accuracy of the measurements obtained[7,10,19-21]. There was concern in establishing the correlation of anthropometric measurements obtained with proven direct and indirect measuring methods with those obtained by the study of the virtual 3-D model [7,22,23], by means of specific tools that software offers.

The difference between the coordinates obtained by a scanner and those obtained by a CMM was negligible. A variation was observed only in one axis in one of the coordinates of the various points assessed. In the same way, the anthropometric measurement performed directly in the head of the mannequin maintained a direct relation with the measurements obtained by means of the software tool.

The use of 3-D models in assessment, planning, and monitoring of patients in the area of plastic surgery is in frank development[2,16]. The possibility of visualizing, for example, the surface of a face at any angle, distance, and lighting by means of 3-D meshes prevents a photographic standard from influencing the evaluation. Characteristics of photography dependent on the quality of the camera, focus, lighting, image definition, background used, and others not only hamper a subjective assessment but also can disrupt an objective comparison of the preoperative and postoperative periods.

In addition to the anthropometric measures established, one can, for example, quantify volumetric measures of asymmetry, geodetic measures (Figure 3), comparison of the deviation of surfaces[18] (Figure 4), the calculation of the area of skin involved, mirroring of images, and many other features with the available software.

Through the use of free specific software such as Blender, CloudCompare, MeshLab, InVesalius, Osirix it is possible to import the files of the meshes, align, style, extract data (Figure 5), and position a 3-D reconstruction of a computed tomography in relation to the mesh of the surface, among other processes. The basic knowledge of graphic computing becomes a tool of fundamental importance.

The following can be cited as clinical applications: the study of face asymmetry; planning of reconstructions with mirroring of the normal side with the affected side (Figure 6); anthropometric comparative study[24] such as in cleft lip and palate[25,26] or rhinoplasty[27]; calculation of expanded skin area when using tissue expander[3]; studies of aging[28]; creation of 3-D molds[29]; monitoring of tumors such as hemangioma[30]; breast volumetry[20]; assessment of filling[24]; simulation of the result of an orthognathic surgery, with the changes transmitted to the surface; and others (Figure 7).

Figure 3. Geodetic measurement performed using the Artec 3D software (measure that accompanies the surface) for a burn area, for assessment in the placement of a tissue expander

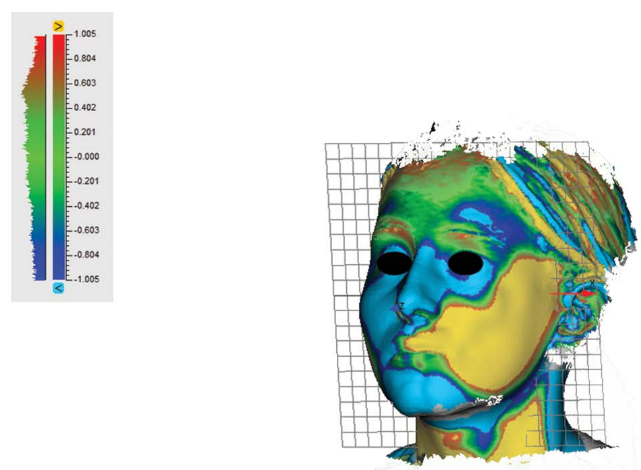

Figure 4. Print screen of the comparison of deviations between surfaces in two meshes of the aligned face performed using the Artec 3D® software, preoperatively and postoperatively, for designing a fat graft for correction of facial asymmetry. The yellow color indicates where there is a difference greater than 1 mm between the two meshes.

Training with surgery simulator haptic devices are also applications of 3-D meshes. Studies have been conducted to develop models that allow deformation of the meshes from virtual reality simulators with instruments that convey a *force feedback* to the user, allowing the simulation of surgical procedures[29-32].

The possibility of having the file in 3-D for a patient allows access to assessments not initially plan-

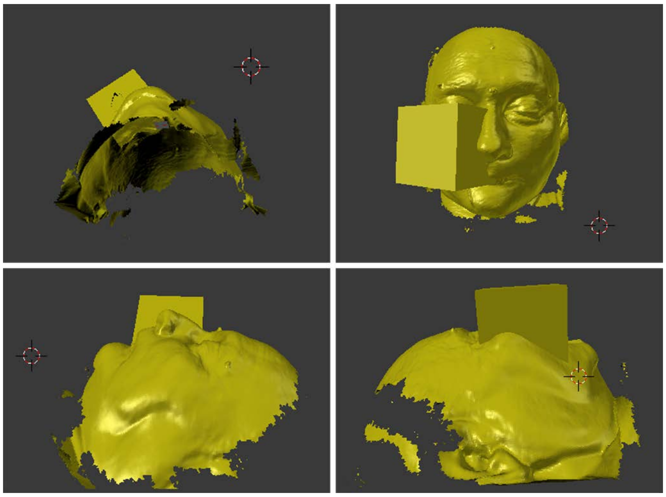

Figure 5. Image performed by using the Blender software for a study developed by the author for volumetric calculation of three-dimensional meshes.

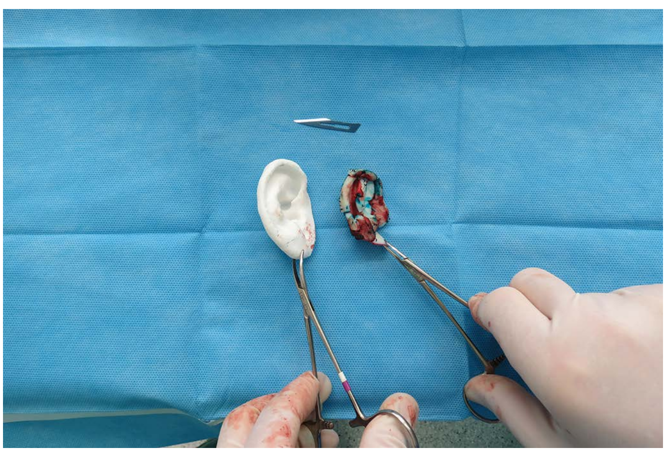

Figure 6. Transoperative photograph of a prototyping ear model for total reconstruction of the patient's ear with right anotia. A capture of the mesh was performed with the Artec 3D structured light scanner, saved in .stl format, exported to the Blender software. Mirroring and modeling were performed to isolate only the ear. The mesh was printed in the CTI - Renato Archer, sterilized, and used in the surgery as a model.

ned in a study, providing not only a technical resource but also a didactic possibility of the physician-patient relationship.

A critical evaluation can be performed in relation to the need of the physician to acquire new knowledge to enable one's own studies. However, current generations are more familiar with the technological innovations and have self-taught experiences in the use of the software.

The cost of a scanner can be a deterrent, but it follows the course of all new technologies, which tend to become cheaper as they are updated. Stereophotogrammetry through photo processing is also possible, performed with *free* software and applications such as 123D.

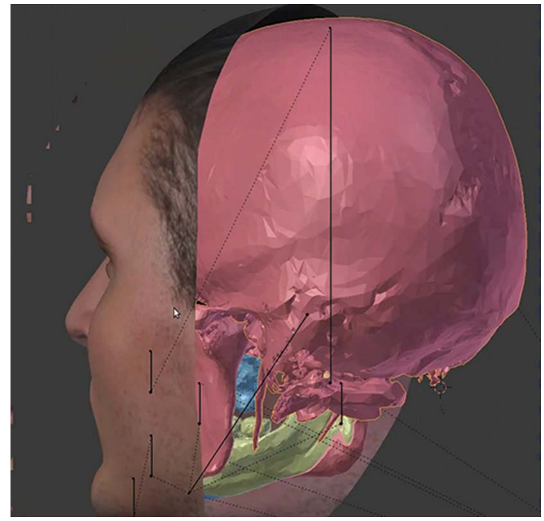

Figure 7. Image performed by using the Blender software. The left posterior lateral vision where the three-dimensional (3-D) reconstruction of a tomography of the cranium and face was positioned along with a 3-D textured mesh for virtual surgery. (Image courtesy of Dr. Everton da Rosa)

CONCLUSION

The conceptual difference between photography and 3-D mesh systems is of fundamental importance for the understanding and introduction of the principles of 3-D technology. The clinical applications of the method have been shown to be reliable and offer features that photography does not allow. There is a promising future in the use of 3-D models in plastic surgery. For consolidate this, we need to continue with new studies and encouragement in the mastery of the technology.

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