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ORIGINAL ARTICLE

Three dimensional models and augmented reality for the study of neuroanatomy

Modelos anatómicos tridimensionales y de realidad aumentada para el estudio de la neuroanatomía

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Abstract

Objective: *Create three-dimensional anatomical and augmented reality models for the study of neuroanatomy, from cadaveric models using photogrammetry for three-dimensional reconstruction, comparing two software, one fully automated and the other semi-automated with classic books for the study of neuroanatomy.* ***Method:*** *Three-dimensional anatomical models were created through the photogrammetry technique and by means of two software. The objects were evaluated by the neurosurgery residents.* ***Results:*** *Three three-dimensional anatomical models were created from photogrammetry for each program and evaluated with a survey applied to 23 neurosurgery residents.* ***Conclusions:*** *There is no significant difference between the 3DF Zephyr© 2021 3Dflow tool for creating anatomical three-dimensional objects in a semi-automated way compared to Autodesk ReCap Photo 22.1 Automated Software© 2021 Autodesk, Inc. The residents consider that the models made in this work are useful in learning neuroanatomy.*

Keywords: *Neuroanatomy. Photogrammetry. Augmented reality images. Three-dimensional. Anatomical models. Anatomy.*

Resumen

Objetivo: *Crear modelos anatómicos tridimensionales y de realidad aumentada para el estudio de la neuroanatomía, a partir de modelos cadavéricos por medio de fotogrametría para su reconstrucción tridimensional, comparando dos software, uno totalmente automatizado y otro semiautomatizado, con los libros clásicos para el estudio de la neuroanatomía.* ***Método:*** *Se crearon modelos anatómicos tridimensionales mediante la técnica de fotogrametría por medio de dos software. Los objetos fueron evaluados por los residentes de neurocirugía.* ***Resultados:*** *Se crearon tres modelos anatómicos tridimensionales a partir de fotogrametría por cada programa y se evaluaron con una encuesta aplicada a 23 residentes de neurocirugía.* ***Conclusiones:*** *No hay diferencia significativa entre la herramienta 3DF Zephyr© 2021 3Dflow para la creación de objetos tridimensionales anatómicos de forma semiautomatizada y el Autodesk ReCap Photo 22.1 Automated Software© 2021 Autodesk, Inc. Los residentes consideran que los modelos realizados en el presente trabajo son útiles en el aprendizaje de la neuroanatomía.*

Palabras clave: *Neuroanatomía. Fotogrametría. Imágenes de realidad aumentada. Tridimensional. Modelos anatómicos. Anatomía.*

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Introduction

The knowledge of human anatomy is one of the cornerstones of medicine and the development of neurosurgery, relying on specific texts for its study, although currently there are very precise descriptions and images that allow its understanding. Due to ethical considerations and the scarcity of donation programs, the exposure of medical students to cadaveric specimens is increasingly lower[1–3], and additionally, for neuroscience residents, the possibility of accessing precise anatomical models is low, and the cadaveric specimens existing in anatomy labs can present significant deterioration due to use and time[4], so the creation of 3D and augmented reality anatomical models through automated techniques, such as photogrammetry, becomes a tool of greater anatomical precision for neurosurgery residents and improves the learning of neuroanatomy[4].

Method

Multiple photographs of the neuroanatomical cadaveric specimens available in the anatomy laboratory of *Universidad El Bosque* (Bogotá, Colombia) were acquired with a Canon EOS Rebel T5i semi-professional camera, under automatic and manual ISO 100 mode parameters, with oscillating exposures f8-f29 and a diaphragm aperture of 4 to 10 seconds of all specimens (360°), following the recommendations established in the online tutorials of 3Dflow Academy. Then, with the photogrammetry technique, which from multiple images previously captured by photography allows the creation of 3D models through software[5], in this case Autodesk ReCap Photo 22.1© 2021 Autodesk, Inc. and 3DF Zephyr© 2021 3Dflow, the 3D reconstruction of the images was performed. The first of the programs only required the uploading of the images to its servers, as the process is automated. With the 3DF Zephyr© 2021 3Dflow program, it is necessary to have a computer capable of processing these images; in our case, a computer with Intel(R) Core(TM) i9-10980XE CPU @ 3.00GHz, RAM 64.0 GB (63.7 GB usable), and NVIDIA GeForce RTX™ 3090 Founders Edition graphics card was used. The semi-automated process was carried out, which consists of an optional manual pre-phase of masking the images to clean image defects and allow better matching of the photographs, which is done by the user, and a subsequent automatic phase for the creation of the three-dimensional object. Each model was evaluated by a professional photographer (Juan Manuel Martínez Segura) who evidenced optimal lighting conditions to be processed in these software.

Finally, these tools were compared to define which was the best three-dimensional and augmented reality model that had optimal precision for the study of its components, based on a survey conducted among neurosurgery residents of Universidad del Bosque, Universidad Militar Nueva Granada, and Hospital General de México, comparing the anatomical models created among them, the images of cadaveric photography, and the diagrams shown in the neuroanatomy guidebooks (Fig. 1).

Subsequently, data were tabulated in a matrix created in Excel, from which a descriptive statistic of the first 8 variables of the survey was performed, and Pearson's correlation coefficient was applied for the comparison between the anatomical models made in the Autodesk ReCap Photo program and those made in the 3DF Zephyr program.

Results

Photographic images with multiple exposure parameters, diaphragm aperture, at ISO 100, of 3 cadaveric specimens (cerebral hemisphere, skull base, and C1 vertebra) were acquired, in a range between 52 and 100 photos depending on the number of areas with irregular shapes, which require a greater number of images, such as the apophyses and foramina at the base of the skull and the cerebral surface. The images were then processed in each of the software for the creation of test 3D models, obtaining three anatomical models per program, that is, 6 in total (Figs. 2-4).

A survey was applied to evaluate and compare the anatomical models to 23 neurosurgery residents, of whom 82.6% were men, aged between 27 and 40 years, with an average age of 30.3 years (Table 1).

Regarding literature preferences for learning neuroanatomy in the skull, 66.6% of the residents use Rhoton's book and 33% use Rhoton, Netter, and Latarjet. Regarding the preferences for the study of neuroanatomy in the spine, most residents prefer Latarjet (44.4%), followed by Anatomy Atlas and Interpretation of Spine Surgery (22.22%) and Latarjet-Carpenter, Springer, and Netter, with 11.11% each[6-10].

A total of 50% of the residents have had the opportunity to use 3D and augmented reality anatomical models for learning neuroanatomy, and 11.1% would

Figure 1. *Setup for taking photographs of cadaveric specimens.*

Figure 2. *Models 1 and 2: cerebral hemisphere*

Figure 3. *Models 1 and 2: C1 vertebra (Atlas).*

Figure 4. *Models 1 and 2: skull base (bony).*

Table 1. Study Population

Variable	n (%)
Sex	
Female	4 (17.39)
Male	19 (82.6)
Year of Residency	
1	2 (8.69)
2	6 (26.08)
3	7 (30.43)
4	5 (21.73)
5	3 (13.04)
Mean Age	30.3 years

not use the models for their training. However, 100% of the residents consider that the models made in the present work are useful in learning neuroanatomy.

Regarding the question "Compared with the cadaveric models you have had at your disposal, do you consider that the 3D and augmented reality anatomical models are a better tool for learning neuroanatomy?", 26% of the residents consider that there is no difference, 21.7% that they are a better tool, and 47.8% that they are a worse tool for learning neuroanatomy.

When comparing the models made (model 1 in the Autodesk ReCap Photo program and model 2 in the 3DF Zephyr program) with the figures shown in the books chosen by the residents as their bibliographic guide, for the cerebral hemisphere model, 47.8% of the residents preferred model 1, 13% model 2, and 30.4% the image from Rhoton's book. For the C1 vertebra model, 43.4% preferred model 1, 43.4% model 2, and 8.6% preferred Latarjet. For the skull base model, 60.8% chose model 2, 60.8% model 2, and 17.3% the image from Netter.

To compare the definition and anatomical precision perceived by the residents, a value was assigned to each variable in the survey for the models made in the present work, with 5 being very good, 4 good, 3 acceptable, 2 bad, and 1 very bad. Pearson's correlation coefficient was applied, and it was evidenced that there are no significant differences in the definition or anatomical precision between the Autodesk ReCap Photo and 3DF Zephyr programs for all the anatomical models made (Table 2).

Discussion

Throughout history, there has been an attempt to refine the knowledge on the composition of the human body. The first contributions are found in the Smith, Ebers, and Brugsch papyri ("the great Berlin papyrus"), written between 3000 and 2500 BC, whose

Table 2. Analysis of Anatomical Accuracy and Image Definition

	Image Definition	Anatomical Accuracy
Average		
Model 1 hemisphere (Autodesk ReCap photo)	3.27	3.36
Average - model 2 hemisphere (3DF Zephyr)	3.04	3.09
p	0.580593089	0.508693651
Average		
Model 1 Atlas (Autodesk ReCap photo)	3.45	3.31
Average - Model 2 Atlas (3DF Zephyr)	3.45	3.22
p	0.682692308	0.822045998
Average		
Model 1 skull base (Autodesk ReCap photo)	4.00	2.30
Average - model 2 skull base (3DF Zephyr)	3.22	3.18
p	0.420147740	0.399507359

contents describe cranial structures. Subsequently, Alcmaeon of Croton and Hippocrates of Cos, in the V and IV centuries BC, respectively, made other anatomical descriptions. On the other hand, Hippocrates is credited with 72 books and 59 treatises, and likewise Aristotle, in that same era, provides information on comparative anatomy and embryology in his writings[1,11,12].

Between 310 and 250 BC, Herophilus of Chalcedon and Erasistratus of Ceos made important research works, enriching the knowledge obtained up to that time about the nervous system and blood and lymphatic vessels. In the time of the ancient Romans, between 670 BC and 480 AD, the greatest source of anatomical knowledge came from wounded gladiators, with Claudius Galen Nicon being the main representative of that time[11,12].

After the end of the Roman Empire, the study of the human body moved to the Middle East during the Islamic Golden Age, between 701 and 1300 AD. In the Renaissance, many anatomical drawings were contributed by artists, among whom Leonardo da Vinci (1452-1519) stands out, who described the cerebral meninges for the first time[1,11,13,14].

Since the late XX century, the urgent need to make changes to the traditional teaching of human anatomy has been raised, so the development of databases and simulators has been promoted, with which closer interactions and a real strengthening of theoretical-practical knowledge in students of both basic sciences and medical-surgical residencies can be achieved, without losing the realism and richness of information that a cadaveric model could provide. Current techniques that employ 3D anatomical study include, in chronological order of appearance, stereoscopy (1920), computed tomography and magnetic resonance imaging (1970), and 3D simulation models or software (1986)[15-18]. The essential characteristic of the latter is that they allow materializing and integrating digital images obtained through photographic, tomographic, or magnetic resonance records, which are subsequently modeled and edited in 3D computers, and finally printed[19-20].

The implementation of 3D anatomical models in the learning of medical students can lead to providing a timely diagnosis and also generate greater analysis of different conditions prior to performing laboratories or imaging, due to the comprehensive knowledge of anatomy[21,22]. They are also of great help in preparing students before starting practices in cadaveric explorations[23-25].

Photogrammetry allows the creation of 3D images with the characteristics of a real model, so it manages to be of great help for the training of medical students or residents, both in surgical skills[17] and spatial reasoning, in comparison with conventional methods[26], as well as in support in the presentation of clinical cases, forums, or congresses.

Conclusions

The present study shows that there is no difference in visual quality or in the perception by the residents between the 3D models created with 2 different applications. Additionally, residents preferred the use of 3D anatomical models over the figures in the guidebooks.

Although 3D models have not yet been fully implemented as the basis for student learning, in this case, neurosurgery residents considered them a very useful in their academic training. It is expected, in the near future, to achieve their implementation for neuroscience students, as they can be a great complement to different bibliographic references to help understand and retain anatomical information[27].

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Conflicts of interests

The authors declare no conflicts of interest.

Ethical considerations

Protection of persons and animals. The authors declare that no experiments have been performed on humans or animals for this research.

Confidentiality, informed consent, and ethical approval. The study does not involve personal data of patients nor does it require ethical approval. The SAGER guidelines do not apply.

Declaration on the use of artificial intelligence. The authors declare that they did not use any type of generative artificial intelligence for the writing of this manuscript.

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