J Med Syst (2017) 41: 83
DOI 10.1007/s10916-017-0728-1

EDUCATION & TRAINING

# 3D Digitization and Prototyping of the Skull for Practical Use in the Teaching of Human Anatomy

**Maria Teresa Ugidos Lozano [1] · Fernando Blaya Haro [2] · Carlos Molino Diaz [2] · Sadia Manzoor [3] · Gonzalo Ferrer Ugidos [4] · Juan Antonio Juanes Mendez [1]**

Received: 23 January 2017 / Accepted: 22 March 2017 / Published online: 6 April 2017


**Abstract** The creation of new rapid prototyping techniques, low cost 3D printers as well as the creation of new software for these techniques have allowed the creation of 3D models of bones making their application possible in the field of teaching anatomy in the faculties of Health Sciences. The 3D model of cranium created in the present work, at full scale, present accurate reliefs and anatomical details that are easily identifiable by undergraduate students in their use for the study of human anatomy. In this article, the process of scanning the skull and the subsequent treatment of these images with specific software until the generation of 3D model using 3D printer has been reported.

**Keywords** 3D printing · Teaching anatomy · Cranium · Rapid prototyping

## Introduction

The study of human bone elements is part of the study program of the course of anatomy in the faculties of Health Sciences. The emergence of new technologies has allowed students to learn the anatomical details, not only with 2D images given in the atlas but using 3D models. These models facilitate a real view of these bones and their relationship with the surrounding structures [1, 2]. The rapid development of these new technologies has also allowed access to the students by means of different technological means, facilitating the dissemination of information [2, 3].

Several studies have demonstrated that students obtained better results when the anatomical study of the bone elements was combined with direct observation of these bone pieces [4, 5]. The deterioration of these bone pieces by continued use, the difficulty in obtaining bone pieces for all students as well as the appearance of the 3D printers at an affordable price for the manufacturing of 3D bones models at full scale has led to the introduction of a new way of studying the anatomy [6, 7]. The emergence of 3D printers has allowed the creation of 3D models by the rapid prototyping technique, which allows the fabrication of three-dimensional structures starting from a Computer-Aided Design (CAD) and an additive manufacturing process [8].

In the present work, rapid prototyping technique has been used for the real-scale reproduction of human skull, using a 3D printer and printing materials to obtain bone models suitable for the use by anatomy students.

## Materials and Methods

Precision scanning was carried out using a contactless laser scanner arm; model FaroArm Scan Platimun (Fig. 1). Point clouds was obtained that represented the bone pieces with great precision and reliability, and converted to a mesh format using special scanning software. Subsequently, through the process of repair and smoothing of the mesh, the final model was obtained for its subsequent 3D printing.

The FaroArm Scan Platimun scanner allowed capturing point clouds with a great performance of point

This article is part of the Topical Collection on *Education & Training*

✉ Maria Teresa Ugidos Lozano

1 Universidad de Salamanca, Salamanca, Spain
2 Universidad Politécnica de Madrid, Madrid, Spain
3 Universidad Complutense de Madrid, Madrid, Spain
4 Universidad Europea de Madrid, Madrid, Spain

**Fig. 1** Digitalization of a bone piece by FaroArm Scan Platimun

acquisition, at high resolution and a precision of ±35 μm. Thus, multiple point clouds were obtained in different positions, for posterior alignment and processing that consisted of millions of points, referenced to a local coordinate system, which represented to-be-modeled anatomical bone with high geometric and dimensional accuracy. This point cloud contained all necessary metric information of the digitized bone model, which was processed using Geomatic Design X. The meshing process by triangulation of scanned points allowed us to pass, from a 3D model formed only by points, to a mesh model constituted by small polygonal planes. This Geomagic Design X supported the import of more than 60 formats and allowed combining CAD data with processed 3D scan data to create solid and editable models such as bone structures, specifically cranium, created in this work.

The methodology used to obtain the final mesh included: elimination of surface noise, correction of overlapping errors, closing of holes, smoothing of faces and optimization of the mesh for additive manufacturing. After the creation of the final mesh, the model was generated in Stereo Lithography (STL) format.

From this model in STL format, we proceeded to additive manufacturing through the successive superposition of micrometric layers of a polymeric material. The software used was "CURA" (Utimaker trading house) allowed us to layer the 3D, according to an optimized configuration profile. These layers are stacked and the model was created automatically or introducing modifications carried out by mathematical calculations using the G-Code generation software and the information was transmitted to the printer to create the cranium (Fig. 2).

For the creation of 3D models, Poly-Lactic Acid (PLA) was employed and printing speed of 40 mm/s was used. This thermoset plastic material, once undergoes the heating-melting process, solidifies with layers resulting in the final model. The hardness and strength of the models obtained are adequate for later use. The machine used in the manufacture was a compact 3D printer branded Colido (model X3045) that integrated an extruder with exchanger of double filament to obtain models of high definition. The resolution of the layer was up to 0.1 mm and the diameter of extruder was 1.75 mm (Fig. 3).

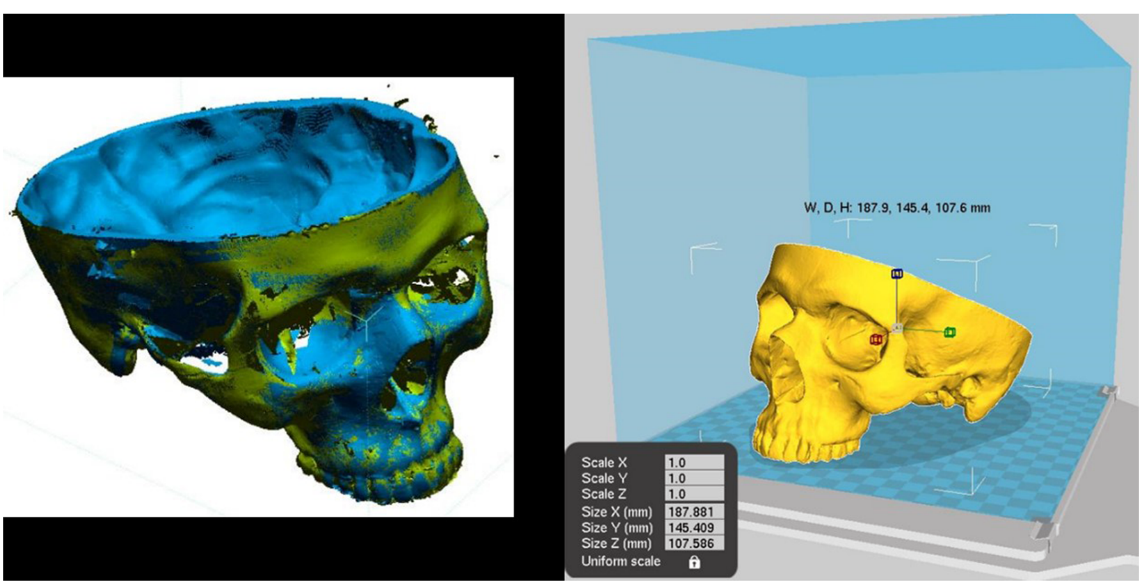


**Fig. 2** Stepwise treatment of cranium using different software

**Fig. 3** Colido X3045 Printer

## Results

The 3D model of the skull obtained in our work presents highly defined and easily identifiable anatomical details that the students of anatomy must know. This can be seen by anatomical details identified in the frontal plane, malar bone, orbits, nasal bones, maxillary and dental insertion. On the base of the skull, styloid processes of the temporal, posterior nasal spine, mastoid process and holes such as the foramen magnum, oval, carotid, jugular, thorny can be observed. Other anatomical details such as bone sutures that are separation between the different bones making up the skull are also identified. From the methodological point of view, the main contribution was to create 3D models of the skull, in real scale of an adult skull so that the students can manipulate and use to identify the anatomical details themselves.

The choice of the FaroArm Scam Platimun scanner allowed us to capture a point cloud with high precision and resolution. The subsequent treatment of this point cloud with the Geomagic Desing 3D allowed us to create mesh and eliminate noise to obtain full-scale designs of the initial model. The Repetier-Host software that was implemented in the 3D Colido X3045 printer transformed the 3D files into commands that were printed. The 3D model that we obtained after the choice of the means chosen for its manufacture, were of low cost, with a hardness and quality suitable for the study of anatomy (Fig. 4).

**Fig. 4** 3D Cranium Model

## Discussion

The undergraduate students of the health sciences faculties need to acquire a broad anatomical knowledge for the further development of their works [9, 10]. Several studies have highlighted the importance of cadaver dissection for the study of human anatomy [6, 11]. According to other studies the best academic results are obtained by combining didactic studies and practical work with cadaveric bone material [9, 11].

The bones used in the study of anatomy, coming from corpses present a progressive deterioration by the continued handling by the students [12]. Despite this deterioration, it is still necessary to be able to identify the anatomical details [13]. The skull is one of the most complex structures at anatomical level with small reliefs and anatomical accidents that are very fragile and its deterioration is very fast [12]. The current difficulties in obtaining cadaveric bone material for the anatomical study has led to the use of new technologies as didactic support to provide an alternative means to deal with problem of deteriorated bone pieces [4, 14, 15]. The creation of 3D models for the study of anatomy became possible after the emergence of Rapid Prototyping technology in the 80's [16, 17]. With this technique, 3D models can be obtained from virtual models using Computerized Axial Tomography (CAT), Magnetic Resonance Imaging (MRI) or hand-held scanners. These images are then treated with Computer Assisted Manufacture (CAD/CAM) and are obtained on 3D axes [18]. There are several rapid prototyping techniques, among them the most commonly used are: [19, 20], 3D printing [20] and Fused Deposition Modeling (FDM) [17]. Some studies also report the errors that occur with this technique [21], however all of them are based on the principle of layer-by-layer addition of the material and represent the anatomical structure that was previously scanned [22]. In this study, various software have been employed, such as Cura software that allowed dividing the 3D model in a layer by layer manner following the profile and details of the model.

The manufacture of 3D printers at an affordable price has allowed the generalization of these 3D models [23]. At their outset, their use was introduced in industries [24], later in biomedicine including advances in biomaterials for their fabrication and employment in different specialties [25–27]. Several works have been published in this field, among them the use in traumatology, design of implants for replacement after trauma or diseases [28] repair of joint tissue [29], bone regeneration by tricalcium phosphate generated by 3D [30] and collagen [31], craniofacial reconstruction [32] and planning of surgical interventions [33–35] are worth-mentioning. In dentistry [36], such as periodontics [37, 38], preoperative guidance in tumors [39], oral and maxillofacial surgery [40, 41].

The use of 3D models in education also includes the training of students in anatomy [42–44]. In our work, we have created a 3D model of a full-scale skull for anatomy study of undergraduate medical students. The material we have used is PLA that provided models with suitable hardness so that the students can use them and models are obtained at an affordable price.

## Conclusions

The 3D model of skull obtained using the addition manufacturing technique in 3D printing with FDM technology reproduce the anatomical details that the students of anatomy must know, with great accuracy and precision. The rapid advancement in the design of increasingly fast and accurate 3D printers as well as the new software that facilitates their use suggests the growing implementation of this technology in the fields of industry, medicine and education. However, the progress in the creation of new materials will be the greatest achievement in the near future.

**Compliance with Ethical Standards**

**Informed consent** Informed consent was obtained from all individual participants included in the study.

**Conflict of interest** There is no conflict of interest.

**Ethical Approval** This article does not contain any studies with human participants or animals performed by any of the authors.

## References


1. Yammine, K., and Violato, C., A meta-analysis of the educational effectiveness of three-dimensional visualization technologies in teaching anatomy. *Anat. Sci. Educ.* 8:525–538, 2015. doi:10.1002/ase.1510.
2. Khot, Z., Quinlan, K., Norman, G. R., and Wainman, B., The relative effectiveness of computer-based and traditional resources for education in anatomy. *Anat. Sci. Educ.* 6: 211–215, 2013. doi:10.1002/ase.1355.
3. Cornwall, J., and Pollard, M. F., Evaluation of free i-applications for tertiary level gross anatomy education. *The Australasian Medical Journal* 5:239–242, 2012. doi:10.4066/AMJ.2012.1249.
4. Juanes, J. A., Hernández, D., Ruisoto, P., García, E., Villarrubia, G., and Prats, A., Augmented reality techniques, using mobile devices, for learning human anatomy. In: *Proceedings of the Second International Conference on Technological Ecosystems for Enhancing Multiculturality* (pp. 7–11). *ACM*: New York, NY, 2014. doi:10.1145/2669711.2669870.
5. Turney, B., Anatomy in a modern medical curriculum. *Ann. R. Coll. Surg. Engl.* 89:104–107. doi:10.1308/003588407X168244 2007.
6. Biasutto, S. N., Ignacio Caussa, L., and Esteban Criado del Río, L., Teaching anatomy: Cadavers vs. computers? *Annals of Anatomy - Anatomischer Anzeiger* 188:187–190, 2006. doi:10.1016/j.aanat.2005.07.007.
7. Baskaran, V., Štrkalj, G., Štrkalj, M., and Di Ieva, A., Current applications and future perspectives of the use of 3D printing in anatomical training and neurosurgery. *Front. Neuroanat.* 10, 2016. doi:10.3389/fnana.2016.00069.
8. McGurk, M., Amis, A. A., Potamianos, P., and Goodger, N. M., Rapid prototyping techniques for anatomical modelling in medicine. *Ann. R. Coll. Surg. Engl.* 79:169–174, 1997.
9. Collipal Larre, E., and Silva Mella, H., Estudio de la Anatomía en Cadáver y Modelos Anatómicos: Impresión de los Estudiantes. *Int. J. Morphol.* 29:1181–1185, 2011. doi:10.4067/S0717-95022011000400018.
10. Rodríguez Ruiz, H. M., Mendoza, D. Z. U., and Gualdrón, A. J., Conocimientos, sentidos y actitudes en relación con la anatomía en estudiantes de segundo año de Medicina. Universidad Nacional de Colombia. 2009. *Rev. Fac. Med.* 58:4, 2010.
11. Azer, S. A., and Eizenberg, N., Do we need dissection in an integrated problem-based learning medical course? Perceptions of first- and second-year students. *Surg. Radiol. Anat.* 29:173–180, 2007. doi.10.1007/s00276-007-0180-x.
12. Villarroel Guerra, M., and Medina Otazo, E., Técnica Anatómica para Restaurar y/o Reproducir Piezas Óseas Humanas de Difícil Obtención, para la Investigación y Docencia Científica. *Int. J. Morphol.* 29:532–536, 2011. doi:10.4067/S0717-95022011000200038.
13. Babinski, M. A., Sgrott, E. A., Luz, H. P., Brasil, F. B., Chagas, M. A., and Abidu-Figueiredo, M., LA RELACIÓN DE LOS ESTUDIANTES CON EL CADÁVER EN EL ESTUDIO PRÁCTICO DE ANATOMÍA: LA REACCIÓN E INFLUENCIA EN EL APRENDIZAJE. *Int. J. Morphol.* 21:137–142, 2003. doi:10.4067/S0717-95022003000200007
14. McLachlan, J. C., Bligh, J., Bradley, P., and Searle, J., Teaching anatomy without cadavers. *Med. Educ.* 38:418–424, 2004.doi:10.1046/j.1365-2923.2004.01795.x.
15. Brenton, H., Hernandez, J., Bello, F., Strutton, P., Purkayastha, S., Firth, T., and Darzi, A., Using multimedia and Web3D to enhance anatomy teaching. *Comput. Educ.* 49: 32–53, 2007. doi:10.1016/j.compedu.2005.06.005.
16. Petzold, R., Zeilhofer, H.-F., and Kalender, W. A., Rapid prototyping technology in medicine—basics and applications. *Comput. Med. Imaging Graph.* 23:277–284, 1999. doi:10.1016/S0895-6111(99)00025-7
17. Petrovic, V., Gonzalez, J. V. H., Ferrando, O. J., Gordillo, J. D., Puchades, J. R. B., and Griñan, L. P., Additive layered manufacturing: Sectors of industrial application shown through case studies.

*Int. J. Protein Res.* 49:1061–1079, 2011. doi:10.1080/00207540903479786.

18. Nogueira, B. A. P., Utilización del prototipado rápido en la odontología. *Revista Estomatológica Herediana* 25(2), 2016. Retrieved from http://www.perurevista.com/index.php/estoma/article/view/3908.
19. Arcaute, K., Mann, B. K., and Wicker, R. B., Stereolithography of three-dimensional bioactive poly(Ethylene Glycol) constructs with encapsulated cells. *Ann. Biomed. Eng.* 34:1429–1441, 2006. doi:10.1007/s10439-006-9156-y.
20. Cohen, A., Laviv, A., Berman, P., Nashef, R., and Abu-Tair, J., Mandibular reconstruction using stereolithographic 3-dimensional printing modeling technology. *Oral Surg. Oral Med. Oral Pathol. Oral Radiol. Endod.* 108:661–666, 2009. doi:10.1016/j.tripleo.2009.05.023
21. El-Katatny, I., Masood, S. h., and Morsi, Y. s., Error analysis of FDM fabricated medical replicas. *Rapid Prototyp. J.* 16*:*36–43, 2010. doi:10.1108/13552541011011695.
22. Kondo, K., Nemoto, M., Masuda, H., Okonogi, S., Nomoto, J., Harada, N., Miyazaki, C., Anatomical reproducibility of a head model molded by a three-dimensional printer. *Neurol. Med. Chir.* 55:592–598, 2015. doi:10.2176/nmc.oa.2014-0436
23. Berman, B., 3-D printing: The new industrial revolution. *Bus. Horiz.* 55:155–162, 2012. doi:10.1016/j.bushor.2011.11.003.
24. Jose, R. R., Rodriguez, M. J., Dixon, T. A., Omenetto, F., and Kaplan, D. L., Evolution of bioinks and additive manufacturing technologies for 3D bioprinting. *ACS Biomater Sci. Eng.*, 2016 doi:10.1021/acsbiomaterials.6b00088.
25. Wang, C., Tang, Z., Zhao, Y., Yao, R., Li, L., and Sun, W., Three-dimensional in vitro cancer models: A short review. *Biofabrication*, 6:022001, 2014. doi:10.1088/1758-5082/6/2/022001.
26. Wu, W., Zheng, Q., Guo, X., and Huang, W., The controlled-releasing drug implant based on the three dimensional printing technology: Fabrication and properties of drug releasing in vivo. *Journal of Wuhan University of Technology-Mater. Sci. Ed.* 24:977, 2009. doi:10.1007/s11595-009-6977-1.
27. Chia, H. N., and Wu, B. M., Recent advances in 3D printing of biomaterials. *Journal of Biological Engineering* 9:4, 2015. doi:10.1186/s13036-015-0001-4.
28. Seitz, H., Rieder, W., Irsen, S., Leukers, B., and Tille, C., Three-dimensional printing of porous ceramic scaffolds for bone tissue engineering. *J. Biomed. Mater. Res. B Appl. Biomater.* 74B:782–788, 2005. doi:10.1002/jbm.b.30291.
29. Sherwood, J. K., Riley, S. L., Palazzolo, R., Brown, S. C., Monkhouse, D. C., Coates, M., … Ratcliffe, A., A three-dimensional osteochondral composite scaffold for articular cartilage repair. *Biomaterials* 23:4739–4751, 2002. doi:10.1016/S0142-9612(02)00223-5
30. Santos, C. F. L., Silva, A. P., Lopes, L., Pires, I., & Correia, I. J., Design and production of sintered β-tricalcium phosphate 3D scaffolds for bone tissue regeneration. *Mater. Sci. Eng. C* 32:1293–1298, 2012. doi:10.1016/j.msec.2012.04.010.
31. Inzana, J. A., Olvera, D., Fuller, S. M., Kelly, J. P., Graeve, O. A., Schwarz, E. M., … Awad, H. A., 3D printing of composite calcium phosphate and collagen scaffolds for bone regeneration. *Biomaterials* 35:4026–4034, 2014. doi:10.1016/j.biomaterials.2014.01.064.
32. Visscher, D. O., Farré-Guasch, E., Helder, M. N., Gibbs, S., Forouzanfar, T., van Zuijlen, P. P., and Wolff, J., Advances in bioprinting technologies for craniofacial reconstruction. *Trends Biotechnol.* 34:700–710, 2016.doi:10.1016/j.tibtech.2016.04.001.
33. Kurenov, S. N., Ionita, C., Sammons, D., and Demmy, T. L., Three-dimensional printing to facilitate anatomic study, device development, simulation, and planning in thoracic surgery. *J. Thorac. Cardiovasc. Surg.* 149:973–979.e1, 2015. doi:10.1016/j.jtcvs.2014.12.059.
34. Mulford, J. S., Babazadeh, S., and Mackay, N., Three-dimensional printing in orthopaedic surgery: Review of current and future applications. *ANZ J. Surg.*2016.doi:10.1111/ans.13533.
35. Marro, A., Bandukwala, T., and Mak, W., Three-dimensional printing and medical imaging: A review of the methods and applications. *Curr. Probl. Diagn. Radiol.* 45:2–9, 2016. doi:10.1067/j.cpradiol.2015.07.009.
36. Alencar, B., Nogueira, P., Roque-Torres, G. D., Meneses-López, A., Bóscolo, F. N., Almeida, D., … Groppo, F. C., Utilización del prototipado rápido en la odontología. *Revista Estomatológica Herediana*, 25:167–174, 2015.
37. Lee, C. H., Hajibandeh, J., Suzuki, T., Fan, A., Shang, P., and Mao, J. J., Three-dimensional printed multiphase scaffolds for regeneration of periodontium complex. *Tissue Eng. Part A*, 20:1342–1351, (2013). doi:10.1089/ten.tea.2013.0386.
38. Carter, S.-S. D., Costa, P. F., Vaquette, C., Ivanovski, S., Hutmacher, D. W., and Malda, J., Additive biomanufacturing: An advanced approach for periodontal tissue regeneration. *Ann. Biomed. Eng.* 45:12–22, 2017. doi:10.1007/s10439-016-1687-2.
39. Darwood, A., Collier, J., Joshi, N., Grant, W. E., Sauret-Jackson, V., Richards, R., … Kirkpatrick, N., Re-thinking 3D printing: A novel approach to guided facial contouring. *J. Cranio-Maxillofac. Surg.* 43:1256–1260, 2015. doi:10.1016/j.jcms.2015.06.001.
40. Yu, H., Shen, S. G., Wang, X., Zhang, L., and Zhang, S., The indication and application of computer-assisted navigation in oral and maxillofacial surgery—Shanghai's experience based on 104 cases. *J. Cranio-Maxillofac. Surg.* 41:770–774, 2013. doi:10.1016/j.jcms.2013.01.016.
41. Fahmy, M. D., Jazayeri, H. E., Razavi, M., Masri, R., and Tayebi, L., Three-dimensional bioprinting materials with potential application in preprosthetic surgery. *Journal of Prosthodontics* 25:310–318, 2016. doi:10.1111/jopr.12431.
42. Pujol, S., Baldwin, M., Nassiri, J., Kikinis, R., and Shaffer, K., Using 3D modeling techniques to enhance teaching of difficult anatomical concepts. *Acad. Radiol.* 23:507–516, 2016. doi:10.1016/j.acra.2015.12.012.
43. McMenamin, P. G., Quayle, M. R., McHenry, C. R., and Adams, J. W., The production of anatomical teaching resources using three-dimensional (3D) printing technology. *Anat. Sci. Educ.* 7:479–486, 2014. doi:10.1002/ase.1475.
44. Lim, K. H. A., Loo, Z. Y., Goldie, S. J., Adams, J. W., and McMenamin, P. G., Use of 3D printed models in medical education: A randomized control trial comparing 3D prints versus cadaveric materials for learning external cardiac anatomy. *Anat. Sci. Educ.* 9:213–221, 2016. doi:10.1002/ase.1573.