DATABASE

Digital science platform: an interactive web application and database of osteological material for anatomy education

Piotr Regulski[1,2*], Jacek Tomczyk[3], Mariusz Białowarczuk[1], Wojciech Nowak[1] and Marek Niezgódka[1]

Abstract

Background: To meet the remote-learning constraints imposed due to the COVID-19 pandemic, the Digital Science Platform was developed. Human anatomy courses require practical classes that involve working on prepared specimens, although access to such specimens has been restricted. Therefore, the aim was to prepare appropriate-quality, scanned 3D model databases of human bone specimens and an interactive web application for universal access to educational materials.

Main body: The database is located on the pcn.cnt.edu.pl website and contains 412 three-dimensional osteological models created via a structured light scanner, tomography and microtomography. The webservice contains a search engine and enables interactive visualization of the models. The database can be accessed, without restrictions, by any student or researcher wishing to use the models for noncommercial purposes. The stored models can be visualized with the open-source VisNow platform, which is also available to download from the webservice. The MariaDB back-end database was deployed, and an Apache server with a personal home page (PHP) frontend was used.

Conclusion: The models in the database are unique due to the specific digitalization process and skeleton specimen origin. Further development of the Digital Science Platform is foreseen in the near future to digitize other valuable materials.

Keywords: Anatomy, Visualization, Education, Digital Science Platform, Pandemic, COVID-19

Background

In the face of the new COVID-19 pandemic teaching and learning conditions, it has become urgent to prepare widely accessible educational materials of adequate quality for universal access [1]. Study programmes for many fields (especially medical and biological programmes) include human anatomy courses. Practical classes require students to work on prepared specimens, which are not always available in teaching centres. This state of affairs is exacerbated by the extreme conditions requiring remote learning during the pandemic [2].

The available literature repeatedly emphasizes the need to move from a 2D representation of anatomical structures in atlases and textbooks to computer-aided 3D visualization [3, 4]. Anatomy education requires an understanding of the position and size of structures in space and involves the identification of landmarks in specimens and clinical images [5]. Three-dimensional digital anatomical models show potential in improving anatomy learning ability and cognition, particularly in students with low spatial visualization skills [6]. Interactive 3D models have a great impact by supporting students with a unique opportunity to employ the models in the training and study process [7]. The incorporation

*Correspondence: pregulski@interia.pl
[1] Center of Digital Science and Technology, Cardinal Stefan Wyszynski University in Warsaw, Warsaw, Poland
Full list of author information is available at the end of the article

Regulski *et al. BMC Medical Education*   (2022) 22:362

Page 2 of 7

of digital technologies provides students with tools to increase their knowledge and better transition from basic to clinical studies [7, 8].

Therefore, the concept of preparing appropriate-quality 3D model databases for universal access to such educational materials was developed. The models represent specimens with a 1:1 scale that were previously available only in lecture halls and can be used by students wishing to learn or expand their knowledge of anatomy.

The presented database includes osteological specimens that can help students master the structure of the human skeleton. The motivation for the development of these specimens is related to the fact that we are currently dealing with an insufficient number of these prepared specimens, the classes during which students have access to them are rather short in duration, and the specimens are rather fragile [9]; this means that students are often tested on bone structures that they have never seen.

The high quality of these models can make them a unique tool for research teams in the preparation of anatomical materials for publication. These models can also be printed on almost all commercially available 3D printers.

The aim was to develop an interactive web application and database containing a dataset of scanned three-dimensional osteological models.

Construction and content

The webservice and database are located on the pcn.cnt. edu.pl website [10] and contain the scanned 3D models of skeletons representing a 1:1 scale compared to real specimens. The specimens originated from a male skeleton aged 35/39 years old. The assessment of skeletal age and sex was made on the basis of skeletal determinants (including skull and pelvis features) used in anthropology [11, 12]. The skeleton came from Radom, from the municipal cemetery that operated during the years 1794–1811.

Several 3D scanning methods were used in the process of digitizing the bone material to obtain the most accurate representation of the surface. Most of the bone models were developed using a handheld structured light scanner [13]. The initial scan data (point cloud) were triangulated, and the obtained 3D models were characterized by their high accuracy and file weight (Fig. 1). The ability to view these data using a web browser (including a mobile version) required a significant reduction in the number of triangles in the model while retaining as much information as possible. In the processes of so-called "retopology", the number of triangles in the models was reduced, and UV maps were prepared [14]. UV mapping is a process involving the projection of a 2D image onto the surface of a 3D model for texture mapping. Textures imitating bone material were also prepared. In cases where the object surfaces were inaccessible to the scanner, tomography was additionally utilized. The results of such tomography were then postproductionally combined with those obtained using the structured light scanner.

A total of 412 bone models are accessible from the webservice. Two hundred six of these are simplified models that can be directly accessed via a web browser with the embedded SketchFab Viewer application programming interface (API) and are available for download directly from the pcn.cnt.edu.pl website. Access to the models in the database is available through the implemented search
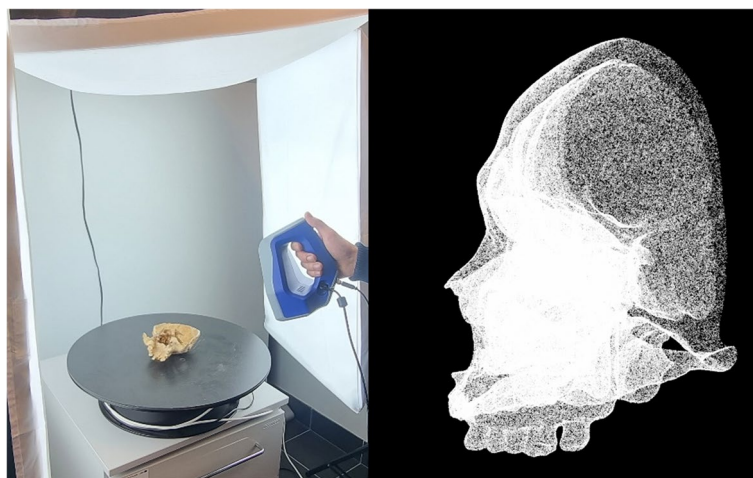

Fig. 1 Process of scanning a handheld structured light scanner. The scan data were obtained as a point cloud from which the model was created. This figure was prepared by the authors

engine or based on hierarchical categories (location of the bone) (Table 1).

Due to the integration of the API, the models are fully interactive. It is possible to rotate, scale, translate and enlarge the selected models in 3D space (Fig. 2). As a result, website implementation involves display optimization for both workstations and mobile devices. It is also possible to adapt the view to virtual or augmented resolution devices. The simplified models placed in the repository are annotated with anatomical structures according to the dictionary of anatomical names. Annotations are available in Latin, English and Polish.

Two hundred six full, unreduced models are stored in the database as a set of files. The geometry is stored in

Table 1 Listing of the osteological specimen with URLs to specific sections of the database

| Section	Models	URL
Cranium	Frontal bone, Parietal bone, Occipital bone, Sphenoid bone, Temporal bone, Auditory ossicles, Maxilla, Mandible, Hyoid bone, Calcified thyroid cartilage Cranium—full model containing nasal bone, lacrimal bone, palatine bone, ethmoid bone, vomer, zygomatic bone, inferior nasal concha	pcn.cnt.edu.pl/en/kosci-czaszki
Vertebral column	Cervical vertebrae C1-C7, Thoracic vertebrae Th1-Th12, Lumbar vertebrae L1-L5, Sacrum	pcn.cnt.edu.pl/en/kregoslup
Thoracic cage	Ribs 1–10, Sternum (Body and Manubrium)	pcn.cnt.edu.pl/en/klatka-piersiowa
Bones of upper limb	Clavicle, Scapula, Humerus, Radius, Ulna, Bones of hand (including Scaphoid, Lunate, Triquetrum, Pisiform, Trapezium, Trapezoid, Capitate, Hamate, Metacarpal bones, Phalanx bones)	pcn.cnt.edu.pl/en/kosci-konczyny-gornej
Bones of lower limb	Coxal bone, Femur, Patella, Fibula, Tibia, Bones of foot (including Talus, Calcaneus, Navicular, Medial cuneiform, Intermediate cuneiform, Lateral cuneiform, Cuboid, Metatarsal bones, Phalanx bones)	pcn.cnt.edu.pl/en/kosci-konczyny-dolnej
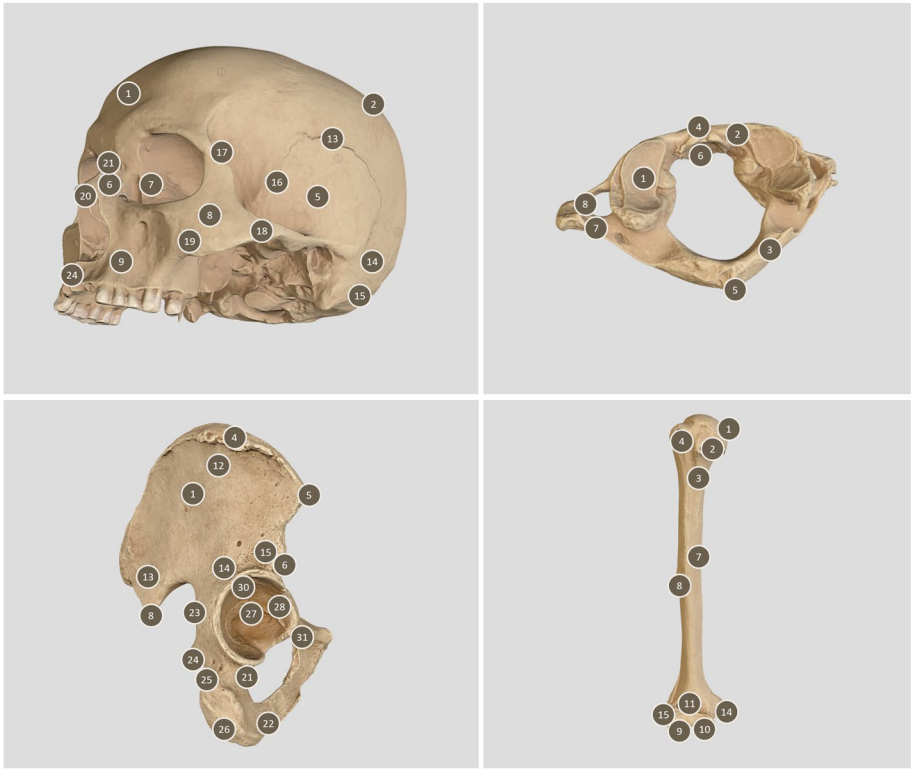
Fig. 2 Example simplified models, available from the website, of the cranium, atlas, hip bone and humerus. This figure was prepared by the authors

the Wavefront obj file format, the UV map in the mtl file format, and the texture in the jpg image format (Fig. 3). The annotations are available from the stored pac files. Access to the models is available after user registration and login. The database can be accessed, without restrictions, by any researcher wishing to use the models for noncommercial purposes. The stored models can be visualized with the open-source VisNow platform, which is also available to download from the webservice, or with any other obj viewer [15].

The database was deployed on the Ubuntu Linux distribution housing MariaDB 10.4 backend database. A virtual machine uses the Apache server (version 2.4) and personal home page (PHP) frontend (version 8.0).

Implications for practice

Several implications for practice for anatomy educators using the Digital Science Platform database can be considered. First, the platform facilitates conducting online classes. Students can browse models themselves, or the

Fig. 3 High-quality, unreduced model of the scapula with a superimposed mesh of triangles. This figure was prepared by the authors

educator can present and analyse anatomical structures during lectures with remote conferencing tools. Second, VisNow software provides the possibility to make virtual cross-sections of the downloaded models, to create simple animations (such as rotations and zooming) and to edit the anatomical landmark annotations. These functionalities are easy to use with the VisNow Viewer 3D module.

Furthermore, the models are based on scanned materials with some lack of bone structures due to their postmortem destruction, which provides an opportunity for the educator to teach students in a similar way as presenting specimens available in the dissecting room. The next important element related to the educational goal of our platform involves observations resulting from the lateralization of the body. The paired structures may show slight anatomical differences resulting from, among other things, the preference to use the right or left side of the body. Therefore, the project presents separate right and left bones (Fig. 4). The models from only one site have annotations, whereas the models from the other site can be used to revise knowledge and testing. This enables students to compare and identify differences between the same bones. Such observations cannot be performed on preparations made of plastics and are unique to models from the Digital Science Platform.

The database and models were used and tested by educators and students. The greatest interest was noted during classes in anatomy, radiology and anthropology, where osteology forms the basis of further education. Academic teachers appreciated the possibility of presenting models in a three-dimensional way and the possibility of testing students' knowledge on models without marked anatomical structures.

The majority of users were students of medicine and dentistry. The database also attracted the attention of physiotherapy, nursing and archaeology students. The website has been positively received by users, which is confirmed by the number of visits of the pcn.cnt.edu.pl. It was viewed 2600 times in the last three months (from January to March 2022) by users from Poland, the United States, the United Kingdom, Germany, the Netherlands, India, and Italy. The most complex models of the cranium and pelvis were the most popular. Students found it much easier to acquire knowledge of the human skeleton thanks to the 3D visualization than with traditional atlas-based methods.

Due to the short period of time from the launch of the database, it has not been trialled; however, future evaluation of the educational utility is planned. Additionally, due to the COVID-19 pandemic and subsequent lockdowns, it was not possible to conduct scientific research using a platform. A survey of anatomy students and
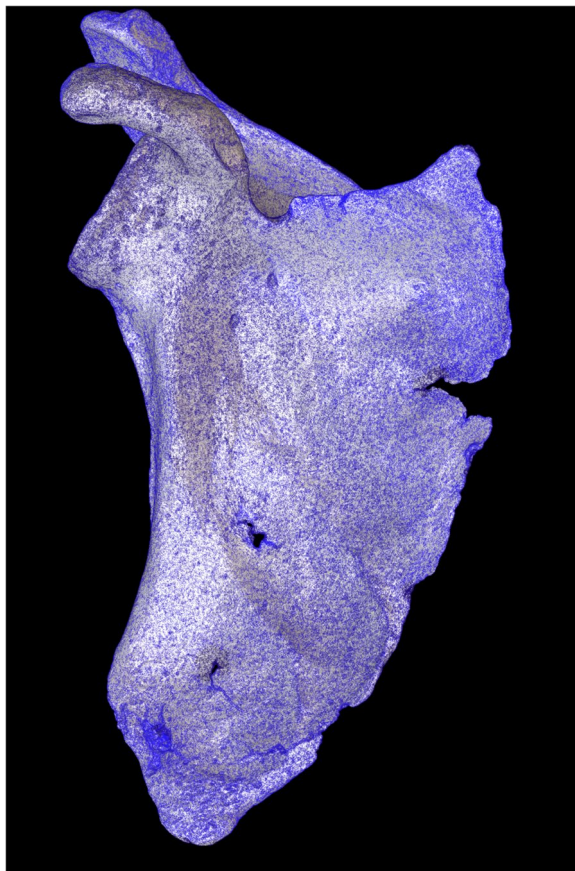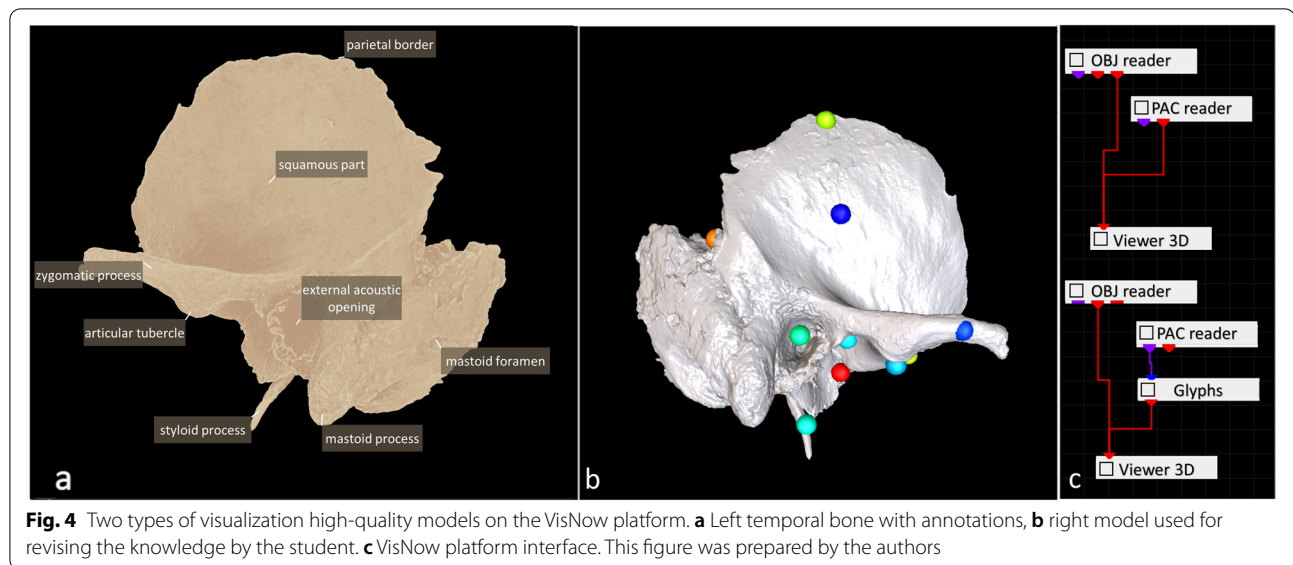
Fig. 4 Two types of visualization high-quality models on the VisNow platform. **a** Left temporal bone with annotations, **b** right model used for revising the knowledge by the student. **c** VisNow platform interface. This figure was prepared by the authors

educators of medical universities is planned and will include an assessment of the possibility of transferring knowledge compared to traditional methods. Experimental studies will be performed among students undergoing gross anatomy practical examinations. Students will be divided into two groups: those utilizing the Digital Science Platform and those using the traditional teaching model. The groups will be compared according to the results of the examination.

The database implications for the research are related to the use of the platform in augmented and virtual reality systems. The deployment of virtual reality engines in combination with three-dimensional anatomical models from the Digital Science Platform will be the subject of research over the next few months.

Utility and discussion

The most unique and valuable benefits of the database are related to osteological specimen access. Students of medical and paramedical faculties can use such specimens not only to learn about the structure of the human skeleton but also, above all, to create a solid foundation of medical knowledge to which they will refer during their further education and through each stage of their professional careers. Undoubtedly, the platform will be most beneficial for students attending human anatomy courses during the first years of studies in university medical faculties [16]. The interactive models will also be useful during radiology classes and clinical subjects in later years of study [8, 17]. The ability to identify anatomical structures is important when training in anthropology or bioarchaeology or for work with exhumation.

The COVID-19 outbreak has changed the perception of teaching anatomy and caused a major educational crisis due to lockdowns and the closure of medical classes [18]. To reduce the risk of the spread of the virus, the accessibility of cadavers and osteological materials was reduced. Many medical universities have reduced the acceptance of bodies during outbreaks because the donor might have been infected with COVID-19, and it was not feasible to test the cadavers [1, 2]. To avoid the risk of infection between students and teachers, most lectures and classes have been delivered online [19, 20]. Therefore, high-quality anatomical models are necessary for remote teaching [21].

It is also worth noting that the prepared bone models are not made of plastic but rather from authentic materials. This means that some fragments of the structures may have been damaged postdeposition. However, such bone fragment loss from the point of exercise is extremely important, as it enables comprehensive testing of anatomy.

The model repository is available to all research teams without restrictions. All the materials on these virtual platforms are stored with unrestricted access, featuring the ability to download each model with a web browser. Therefore, it is possible to reuse the models in research publications or educational materials.

Furthermore, the unreduced models can be viewed and visually analysed with VisNow software, which is available to download from the website after login. The full models contain up to 5 million triangles; therefore, displaying them at full resolution using the website is not possible. The VisNow software provides a rich collection of modules for loading, filtering, mapping,

Regulski *et al. BMC Medical Education*   (2022) 22:362

Page 6 of 7

saving, segmenting, simulating, visualizing and processing the models. It is possible to visualize the bone structures with annotations at any resolution [22].

There are several commercially available [23–27] or free human body atlases [28–30] offering three-dimensionally reconstructed bones. The most unique feature of our database that distinguishes it from other anatomical databases is the possibility of downloading the osteological model and viewing or editing this model in other software. Other services do not allow models to be edited or reformatted [23–30]. Furthermore, osteological material from a real, scanned skeleton was used in the database; other databases are based on models that were created virtually and do not accurately represent the natural surface of the bone. The resolution of the models of other databases is comparable to the simplified models on our platform. However, to the best of our knowledge, none of the databases provides models with the resolution that is available with our unreduced models [28, 29]. Thus, it is not possible to view or print more accurate models from other services.

Further development of the Digital Science Platform will focus on adding new models of other anatomical structures (muscular, nervous, or circulatory systems). It will also include materials from rare osteological pathologies, which would be scanned in a similar manner. Furthermore, radiological models are planned to be added to the platform.

Conclusions

An interactive web application and database of osteological material for anatomy education was developed. High-quality 3D models of anatomical structures are available to download or view on pcn.cnt.edu.pl without restrictions for all research teams and students. These database models are unique due to the specific digitalization process and skeleton specimen origin. Further development of the Digital Science Platform is foreseen in the near future to digitize other valuable materials.

Abbreviations
API: Application programming interface; PHP: Personal home page; UV map: A projection of a 2D image onto the surface of a 3D model for texture mapping.

Authors' contributions
Concept and design: PR, JT, MN; data selection: JT; acquisition, analysis, and creation of models: MB, WN; original draft preparation: PR; critical revision of the article: JT, MN; supervision: PR, JT, MN. All authors have read and agreed to the published version of the manuscript.

Availability of data and materials
The datasets are available without any restrictions in the Digital Science Platform repository, pcn.cnt.edu.pl.

Declarations

Ethics approval and consent to participate
In accordance with Polish law (and particularly with the Act of December 5, 1996, on the professions of physicians and dentists), research on historical materials from excavations does not require the consent of the bioethical committee. The presented skeleton comes from excavations and dates back to the eighteenth and nineteenth centuries. The research and analysis of this skeleton received consent issued by the National Science Centre (No NCN, 2013/11/B/HS3/04117).

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

Author details
[1]Center of Digital Science and Technology, Cardinal Stefan Wyszynski University in Warsaw, Warsaw, Poland. [2]Department of Dental and Maxillofacial Radiology, Faculty of Medicine and Dentistry, Medical University of Warsaw, Binieckiego 6, 02-097 Warsaw, Poland. [3]Institute of Biological Sciences, Cardinal Stefan Wyszynski University in Warsaw, Warsaw, Poland.

References
1. Singal A, Bansal A, Chaudhary P. Cadaverless anatomy: darkness in the times of pandemic COVID-19. Morphologie. 2020;104:147–50.
2. Harmon DJ, Attardi SM, Barremkala M, Bentley DC, Brown KM, Dennis JF, et al. An analysis of anatomy education before and during covid-19: May-August 2020. Anat Sci Educ. 2021;14:132–47.
3. Keenan ID, Powell M. interdimensional travel: visualisation of 3D–2D transitions in anatomy learning. Adv Exp Med Biol. 2020;1235:103–16.
4. Jacquesson T, Simon E, Dauleac C, Margueron L, Robinson P, Mertens P. Stereoscopic three-dimensional visualization: interest for neuroanatomy teaching in medical school. Surg Radiol Anat. 2020;42:719–27.
5. Keenan ID, Ben AA. Integrating 3D visualisation technologies in undergraduate anatomy education. Adv Exp Med Biol. 2019;1120:39–53.
6. Labranche L, Wilson TD, Terrell M, Kulesza RJ. Learning in stereo: the relationship between spatial ability and 3D digital anatomy models. Anat Sci Educ. 2021. https://doi.org/10.1002/ASE.2057.
7. Kazoka D, Pilmane M, Edelmers E. Facilitating student understanding through incorporating digital images and 3D-printed models in a human anatomy course. Educ Sci. 2021;11:380.
8. Smit N, Bruckner S. Towards advanced interactive visualization for virtual atlases. Adv Exp Med Biol. 2019;1156:85–96.
9. Bogomolova K, Sam AH, Misky AT, Gupte CM, Strutton PH, Hurkxkens TJ, et al. Development of a virtual three-dimensional assessment scenario for anatomical education. Anat Sci Educ. 2021;14:385–93.
10. Digital Science Platform. Platforma cyfrowej nauki, Warsaw. 2021. https://pcn.cnt.edu.pl/. Accessed 18 Sept 2021.
11. Tomczyk J, Nieczuja-Dwojacka J, Zalewska M, Niemiro W, Olczyk W. Sex estimation of upper long bones by selected measurements in a radom (Poland) population from the 18th and 19th centuries AD. Anthropol Rev. 2017;80:287–300.

12. Vodanović M, Dumančić J, Galić I, Savić Pavičin I, Petrovečki M, Cameriere R, et al. Age estimation in archaeological skeletal remains: evaluation of four non-destructive age calculation methods. J Forensic Odonto-Stomatol. 2011;29:14–21.
13. Waltenberger L, Rebay-Salisbury K, Mitteroecker P. Three-dimensional surface scanning methods in osteology: a topographical and geometric morphometric comparison. Am J Phys Anthropol. 2021;174:846–58.
14. Pan Z, Di M, Zhang J, Ravi S. Automatic re-topology and UV remapping for 3D scanned objects based on neural network. 31st international conference on computer animation and social agents, 21st-23rd May 2018; Beijing. 2018.
15. Nowiński K, Borucki B. VisNow - a modular, extensible visual analysis platform. 22nd international conference in Central Europe on computer graphics, visualization and computer vision, 2nd-6th Jun 2014; Plzen. 2014.
16. Hoyek N, Collet C, Di Rienzo F, De Almeida M, Guillot A. Effectiveness of three-dimensional digital animation in teaching human anatomy in an authentic classroom context. Anat Sci Educ. 2014;7:430–7.
17. Suárez-Escudero JC, Posada-Jurado MC, Bedoya-Muñoz LJ, Urbina-Sánchez AJ, Ferreira-Morales JL, Bohórquez-Gutiérrez CA. Teaching and learning anatomy Pedagogical methods, history, the present and tendencies. Acta Med Colomb. 2020;45:48–55.
18. Onigbinde OA, Chia T, Oyeniran OI, Ajagbe AO. The place of cadaveric dissection in post-COVID-19 anatomy education. Morphologie. 2021;105:259–66.
19. Iwanaga J, Loukas M, Dumont AS, Tubbs RS. A review of anatomy education during and after the COVID-19 pandemic: revisiting traditional and modern methods to achieve future innovation. Clin Anat. 2021;34:108–14.
20. Stunden C, Zakani S, Martin A, Moodley S, Jacob J. replicating anatomical teaching specimens using 3D modeling embedded within a multimodal e-learning course: pre-post study exploring the impact on medical education during COVID-19. JMIR Med Educ. 2021;7: e30533.
21. Azer SA, Azer S. 3D anatomy models and impact on learning: a review of the quality of the literature. Health Prof Educ. 2016;2:80–98.
22. Visnow.org – Generic visualization and data processing framework in Java. https://visnow.org/. Accessed 19 May 2021.
23. Skeleton - anatomy 3D atlas - human anatomy apps. https://anatomy3datlas.com/en/apps/skeletal. Accessed 19 Sept 2021.
24. Visible body - virtual anatomy. https://www.visiblebody.com/. Accessed 19 Sept 2021.
25. Complete anatomy - advanced 3D anatomy platform. https://3d4medical.com/. Accessed 02 Feb 2022.
26. Biodigital, Interactive 3D anatomy - disease platform. https://www.biodigital.com/. Accessed 02 Feb 2022.
27. Kenhub, human anatomy. https://www.kenhub.com/. Accessed 02 Feb 2022.
28. Artec3D, Human skeleton HD. https://www.artec3d.com/3d-models/human-skeleton-hd. Accessed 02 Feb 2021.
29. Skelet 3D - atlas of bones. http://skelet3d.lf3.cuni.cz/. Accessed 02 Feb 2022.
30. Anatomylearning – 3D anatomy atlas. https://anatomylearning.com/. Accessed 19 Sept 2021.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.