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Meoatlas: Innovating Anatomy Education with 3d Cadaveric Specimen Atlas - A Randomized Controlled Study

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ABSTRACT

Introduction: the scarcity of anatomical specimens is a growing problem in medical education, limiting students' access to essential resources for practical anatomy learning. MeoAtlas, an innovative, cost-free online platform, leverages collaborative efforts from various universities to provide high-fidelity 3D anatomical models. These models are meticulously crafted through photogrammetry using actual human specimens.

Methodology: this randomized controlled trial assessed the efficacy of MeoAtlas by comparing a control group to an experimental group granted early access to the platform during a cardiorespiratory anatomy course. The primary outcome measure was the students' scores on a practical anatomy examination.

Results: the study encompassed 168 medical students. Those utilizing MeoAtlas (the experimental group) achieved superior scores on the practical anatomy examination (mean score 8.4 ± 1.4) versus the control group (mean score 7.9 ± 1.5), with a statistically significant p-value of 0.027. The platform's comprehensive digital anatomical collection was found to notably enhance student engagement and learning outcomes over traditional learning methods.

Conclusion: the MeoAtlas platform was successfully developed and validated, proving to be an innovative and accessible educational tool that improves anatomy teaching through three-dimensional digital resources.

Keywords: Anatomy; Atlas; Photogrammetry.

Introduction

The teaching of human anatomy is an essential pillar in the training of health professionals, establishing the foundation on which knowledge is built in disciplines such as semiology, radiology and surgery. It has traditionally relied on the use of cadavers, facing obstacles such as the scarcity of donations, high maintenance costs and ethical and legal issues that limit their accessibility[1]. Despite being considered the gold standard for this field of study[2], the reliance on cadavers has been questioned, leading many institutions to look for alternatives[3,4].

Computational advances have revolutionized anatomy teaching with technologies that allow three-dimensional representations to better understand the spatial relationships of the human body. Educational anatomy apps, accessible on mobile devices and PCs, have turned anatomical atlases into interactive tools[5]. With manipulable 3D models, they promote immersive and flexible learning, freeing students from the limitations of traditional laboratories and two-dimensional atlases[6].

MeoAtlas, a free online anatomy teaching platform, represents a breakthrough in the educational field by combining traditional teaching methods with technological innovations. The platform stands out for hosting high-precision 3D anatomical models provided collaboratively by universities, created by photogrammetry from real specimens dissected by experts (Figure 1). Developed to address the growing shortage of cadavers available for anatomy teaching, MeoAtlas aims to preserve and make available a digital collection of anatomical specimens with an ethical and responsible commitment to sensitive material. As well as facilitating remote access to content, MeoAtlas enriches learning with an interactive 3D approach. Features such as the addition of anatomical terms and customized quizzes make it a complete tool for teaching anatomy, enabling knowledge acquisition, retention and evaluation.

The name MeoAtlas reflects the concept that each user can contribute and "own" a part of the shared knowledge, making learning a collaborative experience. The aim of this study is to validate this platform as an innovative and accessible educational tool for teaching anatomy

Materials and Methods

Following the development of the MeoAtlas platform and the creation of a significant collection of 3D anatomical parts, an objective and subjective validation study was carried out with medical students.

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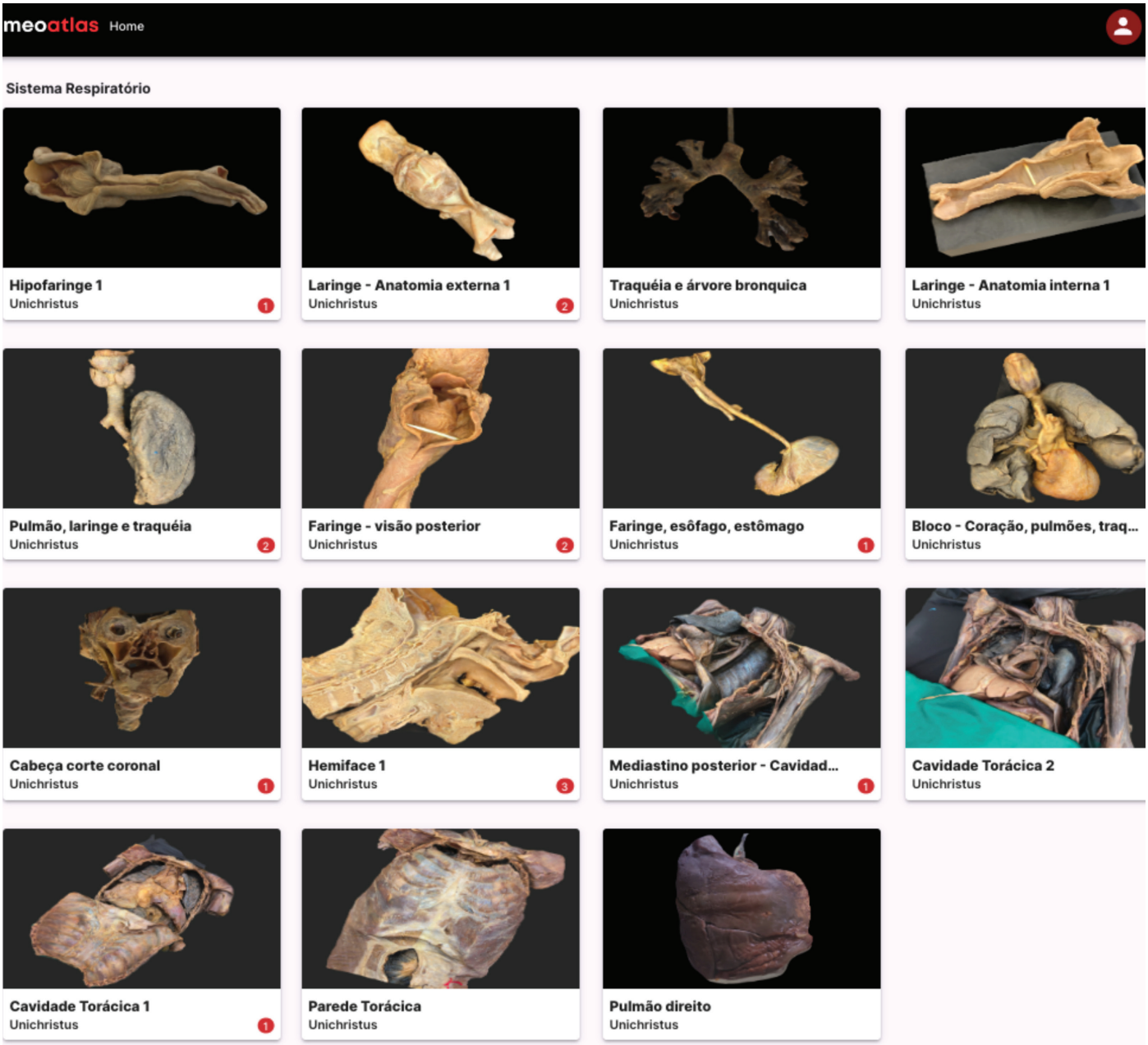

Figure 1. 3D Anatomical Specimen Collection of Respiratory System

This is a randomized controlled study that compared a group of students who had access to the MeoAtlas platform for individual study with a control group during the course of anatomy of the respiratory and cardiovascular systems. The parameters evaluated included the marks obtained in the anatomy practical tests, the time spent engaging with the platform and the answers about usability.

The project was approved by the Ethics Committee of the Christus University Center - Unichristus under protocol number 6.479.597. The work was carried out in accordance with the principles and standards that regulate research on human beings, of the National Health Council - Ministry of Health, Resolution No. 466/2012. The authors state that every effort was made to follow all local and international ethical guidelines and laws that pertain to the use of human cadaveric donors in anatomical research.

First semester medical students at Unichristus were invited to take part in the research on the first day of the course. The two classes of the first semester of Medicine, each with 100 students, were initially formed by a stratified randomization process based on the entrance exam classification, separating students with even and odd classifications. To determine which class would have exclusive access to the MeoAtlas platform (experimental group) and which would follow the traditional curriculum without access to the application (control group), an additional draw was made. This specific strategy was adopted in order to minimize the risk of sharing passwords and access between the groups. By assigning an entire class to

each condition of the study, advantage was taken of the previous stratified randomization in the entrance exam to maintain the integrity of the experimental design, while at the same time reducing the chances of interference between the groups.

The period analyzed comprised the 5 weeks dedicated to the cardio-respiratory system, including 6 theoretical anatomy classes and 4 practical classes in the laboratory, as well as classes in other basic sciences such as histology, embryology and physiology related to the subject. This subject is the last in the first semester of the Medicine course, before which the students studied the locomotor system and took 4 practical anatomy exams. The anatomy laboratory where the study was carried out has excellent quality anatomical specimens, both glycerinated and plastinated, in adequate quantity for the study. However, students only have access to cadaveric specimens during practical classes or in weekly sessions with monitors. Students are given a practical test at the end of the course, consisting of 20 gymkhana-style questions, where one anatomical structure is pointed out per question and students must name it.

For the experimental group, access credentials and the link to access the platform were sent by e-mail after confirming that they had signed the informed consent form. When accessing the tool for the first time, the student agreed to the terms of use and privacy policies. At the end of the course, the Anatomy practical test scores from both classes were collected and used to compare the experimental group and the control group

During the research period, strict access control measures were implemented. Only students from the experimental group and the main researcher were allowed access to the platform. All new registration requests were carefully filtered to ensure that only eligible participants from the experimental group could use the platform, maintaining the integrity of the study methodology.

The survey registration questionnaire included questions aimed at segmenting the sample, such as: age, gender, experience with anatomy, experience with anatomy apps. In addition to the demographic questions, the registration questionnaire includes a section dedicated to evaluating the students' experience and background in relation to the subject of Anatomy, such as the study methods adopted by the students and their perception of the level of difficulty of the subject. Specific metrics were collected to understand the pattern of use of MeoAtlas. This includes the date and duration of each session, the number of anatomical parts viewed and the number of quizzes taken.

The grades obtained in the anatomy practical exams were collected at the end of the academic semester, including the history of grades prior to the survey for a broader context of the analysis. After completing the course, the students in the experiment group were invited to take part in a subjective evaluation of the MeoAtlas platform.

Results

Of the 200 students initially invited to take part in the research, 168 accepted the invitation, divided into 79 in the control group and 89 in the experiment group (Table 1). There was no statistically significant difference between the two groups in all demographic analyses. The average age of the participants was 21.3 years with a standard deviation of 5 years. As for gender, 66.1% of the participants were female, totaling 111 individuals. With regard to familiarity with technology, 64.3% of the participants reported having had contact with 3D anatomy applications. When asked about the use of applications in the study of anatomy, 47% of the participants said they used this technology. The perception of the difficulty of anatomy showed that 12.5% of the participants considered the subject difficult or very difficult. Regarding the time spent studying anatomy, 63.6% of the participants reported studying for 2 hours or more a week.

Table 2 shows the results obtained when comparing test scores between the control group and the experiment group throughout the study (Table 2). Regarding the theoretical assessments, which include knowledge of basic sciences other than anatomy, the grades of the students in both groups showed no statistically significant differences. The averages were 6.6 ± 1.3 and 6.9 ± 1.2 for the control and experiment

Table 1. Demographic characteristics of the survey participants.

	Total	Control group	Experiment group	p*
n	168	79	89	
Age	21,3 ± 5	21,8 ± 5,7	20,9 ± 4,3	0,696
Female gender	66,1% (111)	64,6% (51)	67,4% (60)	0,821
Previous contact with an anatomy app	64,3% (108)	68,3% (54)	60,7% (54)	0,302
Use apps to study anatomy	47% (79)	48,1% (38)	46,1% (41)	0,792
Finds anatomy difficult or very difficult	12,5% (21)	13,9% (11)	11,2% (10)	0,161
Studies anatomy 2 hours or more per week	63,6% (107)	63,3% (50)	64,0% (57)	

*Age = Mann-Whitney test, other variables = Chi-square

Table 2. Comparing test scores between the 2 groups.

	Controle group n (79)	Experiment group n (89)	p
First theory test	6,6 ± 1,3	6,9 ± 1,2	0,139
Last theory test	7,2±1,3	7,4 ± 1,0	0,719
Practical test 1	6,5 ± 1,6	6,2 ± 1,7	0,279
Practical test 2	7,9 ± 1,4	8,0 ± 1,4	0,684
Practical test 3	8,0 + 1,3	8,2 ± 1,6	0,122
Practical test 4	5,2 ± 1,9	5,2±2,0	0,613
Average of the previous 4 tests	6,9 ± 1,2	6,8 ± 1,4	0,967
Practical test 5 (Intervention)	7,9 ± 1,5	8,4 ± 1,4	0,027*
Difference Test 5 and history	0,9 ± 1,4	1,5 ± 1,2	0,003*

*Statistically significant result - p<0.05, Mann-Whitney test

groups in the first theory test, and 7.2 ± 1.3 and 7.4 ± 1.0 in the last, respectively.

During the first anatomy practical assessments, the mean scores for the control group and the experiment group were consistently similar in the first four tests, with 6.9 ± 1.2 and 6.8 ± 1.4, respectively. These results indicate that there were no significant differences between the groups before the intervention with the MeoAtlas platform. However, in practical test 5, taken after the platform was introduced, there was a statistically significant difference in the students' scores. The experiment group, which had access to the MeoAtlas platform, performed better, with an average of 8.4 ± 1.4 compared to 7.9 ± 1.5 for the control group, and a p-value of 0.027. The difference between the scores of practice test 5 and the historical averages was more pronounced in the experiment group, with an average improvement of 1.5 ± 1.2, significantly higher than the improvement of 0.9 ± 1.4 observed in the control group, with a p-value of 0.003.

These results indicate that, while overall performance in the theory tests and the first practical tests was not significantly different between the groups, the use of the MeoAtlas platform had a positive impact on the students' performance in the practical test following its implementation. This increase in grades suggests that the MeoAtlas platform can be a valuable tool for improving practical anatomy learning.

The subjective evaluation of the MeoAtlas platform by students provides a comprehensive view of the perceived impact on anatomy learning. A large majority of users, 81.5%, rated the quality of the digital anatomical pieces as high or very high, which suggests a high level of satisfaction with the representation of anatomical structures. With regard to the clarity of the study of anatomy, 92.1% of participants felt that the platform helped to make the content more comprehensible, indicating that it can facilitate a better understanding of the subject. In addition, 76.9% of students considered the platform superior or much superior compared to other study methods, which highlights the perceived value of MeoAtlas as an innovative educational tool.

92.3% of students agreed that MeoAtlas contributes significantly to learning anatomy. The platform also received a strong endorsement from students in terms of recommendation, with 95.3% saying they would recommend it to others, reflecting confidence in the tool's educational potential.

Motivation is a key factor for effective study, and 84.6% of users indicated that the platform increased their motivation to study anatomy. This suggests that MeoAtlas can play a positive role in engaging students with the subject. Usability is a crucial aspect for any educational application, and 55.3% of users reported that the platform is easy to use, highlighting MeoAtlas' accessibility and user-friendly interface. As for the application's performance, 67.6% rated it as excellent or good, reinforcing the technical effectiveness and stability of the platform. Finally, 59.3% of participants reported that they spent more or much more time studying anatomy as a result of using the app. These subjective results demonstrate a positive reception and indicate success not only as a complementary learning tool, but also as a means of stimulating greater dedication and enthusiasm for the study of anatomy among medical students.

Analysis of the pattern of use of the MeoAtlas platform reveals relevant data on student engagement with the tool (Table 3). With 27 anatomical parts available, there were a total of 1267 views of the parts, indicating active use of the available resource. In addition, 47 of the students' own views were created, which reflects the platform's interactive functionality in allowing users to customize and deepen their study.

The sharing feature was also put to good use, with 387 views of other users' views, highlighting the collaborative aspect of MeoAtlas. The quizzes, which are essential for self-assessment and retaining content, also had a significant take-up: 435 quizzes were started, of which 384 were completed, resulting in an impressive total of 5186 questions answered.

Table 3. Metrics extracted from the platform database.

Available anatomical parts	27
Views of anatomical parts	1267
User-created visions	47
Views of user-created visions	387
Quizzes started	435
Quizzes completed	384
Questions answered	5186
Accessed the app	67,4% (60)
Average usage time in minutes	136 (1-1052)
Average number of anatomical parts per student	22,2 (1-148)
Average number of quizzes taken	8,7 (0-68)

Of the total number of students, 67.4% accessed the platform at least once, which may indicate a positive acceptance of MeoAtlas as a complement to traditional study methods. The average time of use per student was 136 minutes, with a considerable variation from 1 to 1052 minutes, suggesting that some students used the platform extensively, while others used it more moderately.

As for interaction with the content, each student explored an average of 22.2 anatomical specimens, ranging from a single specimen to involvement with almost the entire collection available. This shows that students are engaged in exploring the variety of resources on offer. The average number of quizzes taken per student was 8.7, with some students taking up to 68 quizzes, which demonstrates the use of this interactive tool to reinforce learning.

Discussion

Analysis of the results reveals that, prior to the introduction of MeoAtlas, there were no significant differences between the control and experiment groups in the first anatomy practical assessments, with similar grade point averages. However, after the implementation of MeoAtlas, the experiment group showed significantly better performance in the fifth practical test, with higher average marks compared to the control group. This increase in performance can be attributed to the positive impact of MeoAtlas on the learning process, as evidenced by the 92.3% of students who agreed that the platform contributed significantly to their learning of anatomy. Additionally, 84.6% of users reported an increase in motivation to study anatomy, indicating that access to the platform may have encouraged a deeper and more effective engagement with the study material.

Other studies have also reported that incorporating gamification elements, such as creating your own view of the anatomical part and quizzes, proves to be an effective approach to improving student motivation and performance in complex fields such as anatomy[8,9]. Gamification not only promotes a more engaging learning experience, but also facilitates long-term knowledge retention, which is essential for understanding medical anatomy[10]. Therefore, the high percentage of students who reported MeoAtlas' significant contribution to their learning and increased motivation to study anatomy indicate the platform's potential to enrich the educational process.

The use of three-dimensional anatomical models and the photogrammetry technique in anatomy education are not recent innovations[11]; however, MeoAtlas' approach of integrating these technologies into an interactive online platform represents a significant advance. Historically, the use of 3D digital models in anatomy has facilitated the understanding of complex bodily structures, allowing students a spatial and detailed view of anatomical structures[12]. Photogrammetry, in turn, enriches this process by converting photographic images of anatomical parts into precise digital models, offering a reliable and accessible representation of physical characteristics.

Unlike international alternatives such as Visible Body, Anatomy Learning and Anatomy Atlas 3D which are predominantly paid for with costs ranging from R$89 for a one-off fee to R$199 per year, MeoAtlas presents itself as a more inclusive and affordable solution (Figure 2). The innovative proposal gains even more relevance when considering the specific needs of medical training in contrast to other health courses. While 3D models designed by designers can be sufficiently detailed and educational for courses in areas such as nursing, physiotherapy or dentistry, where a general understanding of anatomy can meet curriculum requirements, medical training demands a more in-depth and detailed approach. MeoAtlas, by incorporating real digitized anatomical parts, offers a more faithful and diverse view of human anatomy, which is essential for future doctors. This is crucial as it allows medical students to explore the anatomical variability inherent in the human population, better preparing them for the diagnostic and surgical challenges they will encounter in their professional practice.

Conclusion

The MeoAtlas platform was successfully developed and validated, proving to be an innovative and accessible educational tool that enhances anatomy teaching through three-dimensional digital resources. Evaluation of the impact on academic performance showed significant improvements in practical grades and an increase in student engagement, indicating that the platform can effectively enrich the educational experience in anatomy.

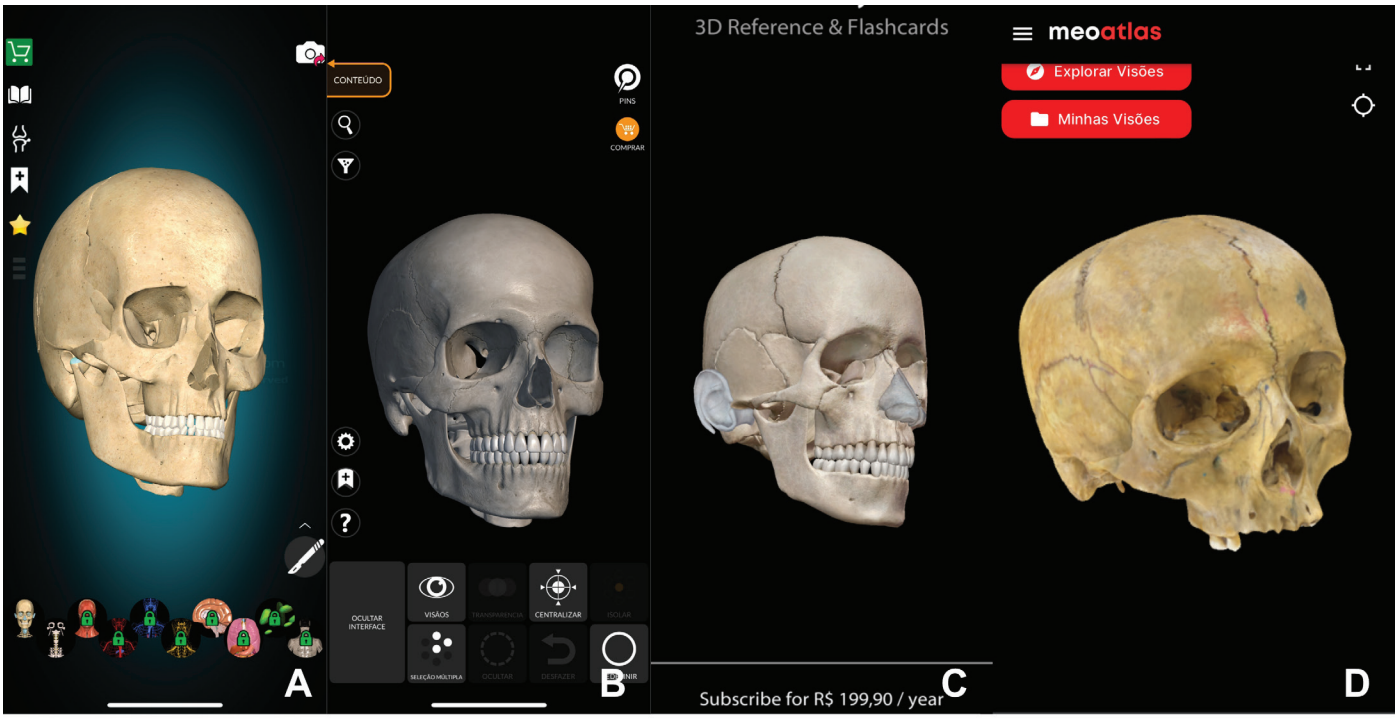

Figure 2. Apps: A - Anatomy Learning / B - Anatomy Atlas 3D / C - Visible Body / D MeoAtlas

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Ethics Statement

The authors state that every effort was made to follow all local and international ethical guidelines and laws that pertain to the use of human cadaveric donors in anatomical research (Iwanaga *et al.*, 2022).

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Mini Curriculum and Author's Contribution

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