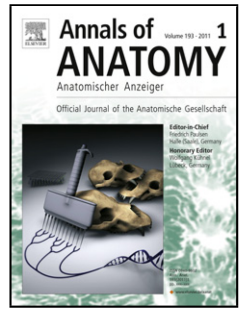
Accepted Manuscript



Title: 3D-Printed specimens as a valuable tool in anatomy education: A pilot study

Authors: Monique Garas, Mauro Vaccarezza, George Newland, Kylie McVay-Doornbusch, Jamila Hasani

PII: S0940-9602(18)30075-X
DOI: https://doi.org/10.1016/j.aanat.2018.05.006
Reference: AANAT 51278

To appear in:

Received date: 20-12-2017
Revised date: 6-4-2018
Accepted date: 15-5-2018

3D-PRINTED SPECIMENS AS A VALUABLE TOOL IN ANATOMY EDUCATION: A PILOT STUDY

Monique Garas, Mauro Vaccarezza#*, George Newland#, Kylie McVay-Doornbusch, Jamila Hasani

School of Pharmacy and Biomedical Sciences, Faculty of Health Sciences, Curtin University, Bentley, Perth, WA 6102, Australia.

Joint senior authorship.

*Corresponding author: Dr. Mauro Vaccarezza, M.D. Ph.D., School of Pharmacy and Biomedical Sciences, Faculty of Health Sciences, Curtin University, Bentley, Perth, WA 6102, Australia.

Email: mauro.vaccarezza@curtin.edu.au

ABSTRACT

Three-dimensional (3D) printing is a modern technique of creating 3D-printed models that allows reproduction of human structures from MRI and CT scans via fusion of multiple layers of resin materials. To assess feasibility of this innovative resource as anatomy educational tool, we conducted a preliminary study on Curtin University undergraduate students to investigate the use of 3D models for anatomy learning as a main goal, to assess the effectiveness of different specimen types during the sessions and personally preferred anatomy learning tools among students as secondary aim. The study consisted of a pre-test, exposure to test (anatomical test) and post-test survey. During pre-test, all participants (both without prior experience and experienced groups) were given a brief introduction on laboratory safety and study procedure thus participants were exposed to 3D, wet and plastinated specimens of the heart, shoulder and thigh to identify the pinned structures (anatomical test). Then, participants were provided a post-test survey containing five questions. In total, 23 participants completed the anatomical test and post-test survey. A larger number of participants (85%) achieved right answers for 3D models compared to wet and plastinated materials, 74% of population selected 3D models as the most usable tool for identification of pinned structures and 45% chose 3D models as their preferred method of anatomy learning. This preliminary small-size study affirms the feasibility of 3D-printed models as a valuable asset in anatomy learning and shows their capability to be used adjacent to cadaveric materials and other widely used tools in anatomy education.

Keywords: Gross anatomy education, 3D printing, medical education, anatomical models, 3D imaging techniques, multi-color 3D printing, human

INTRODUCTION

Anatomy education is primarily based on the use of lecture materials, atlases, cadaveric materials such as wet and plastinated materials as well digital imaging resources (Winkelmann, 2007; Louw et al 2009; Papa and Vaccarezza, 2013; Chan and Pawlina, 2015; Bergman, 2015;

Estai and Bunt, 2016; McBride and Drake, 2018). These materials have formed the fundamental base of the traditional method of anatomy education.

Of note, traditional methods of anatomy study such as dissection and prosection have been used for centuries and are still used in modern medical curriculum (Winkelmann, 2007; Louw et al 2009; Chan and Pawlina, 2015, Ghosh, 2017; McBride and Drake, 2018). A sound knowledge of gross anatomy is needed for clinical practice and is preliminary to surgical training and proper execution of surgical procedures (Sugand et al, 2010). Moreover, a three-dimension view and feeling of human body is considered of paramount importance in anatomy education (McLachlan et al 2004; Older, 2004) and cadaveric dissection/prosection is still considered the most appropriate resource to reach these goals (Winkelmann, 2007; Patel and Moxham, 2008).

However, there are numerous problems associated with the use of this traditional method such as costs associated with obtaining and preservation of human cadavers, maintenance of anatomy laboratories, ethical, legal and religious issues relating to donor bequest programs, the use of cadaverous materials based on different cultural and religious backgrounds and ensuring safety of students and staff (Bergman, et al 2008: Bergman, 2015; McMenamin, et al 2014: Lim, et al., 2016; Chan and Pawlina, 2015; Vaccarezza & Papa, 2013; Estai and Bunt, 2016). Furthermore, plastination is a time-consuming process where the production of plastinated specimens take several weeks to months and such models do not always give the actual representation of anatomical structures. Age, disease or obesity are other factors that reduce the suitability of cadavers for dissection or potentially impair production of a good quality specimen.

In addition to traditional methods (dissection and plastination), a modern technique of a three-dimensional (3D) printing system has recently been introduced into anatomy curriculum

(McMenamin et al; 2014, Lim, et al., 2016; Vaccarezza and Papa, 2015; Azer and Azer, 2016). This new tool appears promising and could support and surrogate more traditional methods in anatomy education.

Recent relevant studies assessing the impact of different pedagogies (Losco et al., 2017; Wilson et al 2018; Vaccarezza, 2018) in anatomical education highlight the potential role of new methods (such as the use of 3D-printed material) in learning and teaching anatomy: 3D-printed specimens could be an adjunct valuable tool particularly in contexts where human dissection is hampered by lack of facilities, human material and by a problematic cultural and /or religious background (McMenamin et al, 2014, Bergman et al. 2015).

Our preliminary pilot study based on a small cohort of undergraduate biomedical students at Curtin University (Perth, Australia) aimed to assess *in primis* the usability of 3D-printed models as a suitable anatomy educational tool and as subsidiary aim to investigate the effectiveness of the different types of specimens (wet, plastinated, 3D-printed model) as learning tools in anatomy education and to investigate student's personal preferences (wet, plastinated, 3D-printed models) as learning tools in anatomy education.

2. MATERIALS AND METHODS

The study involved 23 participants in total; 11 students from 1st year "Health Science" courses formed the without prior experience- group whilst 12 students from 3rd year "Human Biology Preclinical" course formed the experienced group. Inclusion criteria were that the participating students had to be undergraduate from the 1st year course or 3rd year courses from the Faculty of Health Sciences at Curtin University. Exclusion criteria were the achievement of the graduate student level, or having had previous exposure to anatomy and anatomical specimens outside of the university curriculum, as well as being pregnant at the time of the study to avoid potential hazardous chemical exposure.

Both, without prior experience and experienced groups were exposed to plastinated, 3D-printed models and cadaverous specimens of the external heart, shoulder and thigh. 3D-printed models were obtained from Curtin University Medical School where they were purchased from Mentone Educational, Springvale, Victoria. Traditional specimens (wet and plastinated) had previously been dissected and plastinated by laboratory staff and had been used for teaching and learning purposes in Curtin anatomy laboratories.

Each student was exposed to three stations. Station 1 contained plastinated specimens of the external heart, shoulder and thigh, station 2 contained 3D-printed models of the external heart, shoulder and thigh and station 3 contained wet specimens of the external heart, shoulder and thigh. Each station contained 3 specimens and for each specimen one question was proposed. A maximum of three laboratory sessions were conducted during the pilot study and each laboratory session consisted of a maximum of nine students. Photos of each station with the related specimen are available in Supplement 1.

2.1 Pre-test

All participants were sent formal emails prior to the study regarding study date, time, location and personal protective equipment (i.e. lab coat and no electronic devices). Participants were given a short introduction on laboratory protocol and study design by research team members on the day of study. Participants were advised to let research members know if they felt unwell when exposed to the anatomical specimens to minimize the likelihood of risks associated. However, no such incidents were experienced.

2.2 Exposure to test

All participants were provided the same anatomical test paper containing nine questions related to specimen materials; external heart, shoulder and thigh. Participants were asked to identify the pinned structure on the specimen within two minutes with the help of a fully labelled diagram provided per station. The use of the labelled diagram ruled out the testing of anatomical knowledge. Each question was associated with a Likert scale rating of 1-5 in which the participants had to rank how easy (1) or how hard (5) it was to identify the structure. Participants were asked to move to the next station after the alarm buzzed. The Test questions and Likert scale questions are available as supplementary material (Supplement 2).

2.3 Post-test

All participants were provided a post-test survey containing five questions based on a Likert scale. The survey primarily assessed participants' attitudes towards the use of the 3D-printed models in comparison to traditional specimens (plastinated and wet). It also investigated participants' personal preference on the use of different specimen types and if they would support the use of 3D-printed models in anatomy curriculum. Post test questions are available as supplementary material.

2.4 Data analysis

Data collected from the test paper and post-test survey were collated and further analyzed using categorical analyses, bar graphs, Chi Square test and contingency table. The statistical program used was JMP11® SAS Institute and JMP14® SAS Institute (SAS Institute Inc., Cary, NC, USA).

2.5 Ethics approval and recruitment

Ethics approval was granted by the Curtin University Human Research Committee (project number HRE2016-0268). All study data obtained were stored together and remained confidential. Students' participation was completely voluntary and informed consent was obtained from each student prior to the study. Once ethics was approved, students were recruited via blackboard posts, visits to health science classes and the distribution of flyers around campus.

RESULTS

All 23 participants completed the test paper and post-test survey. The test questions had two components, (a) relating to accuracy of identification, and (b) ease of use in locating anatomical features. They were scored as (a) right or wrong, and (b) using a 5-point Likert scale, in which 1 was the easiest and 5 the hardest to use.

Test paper

Fig. 1A, 1B and 1C display the average Likert scale scores for each experimental group. Fig. 1A is associated with questions 1-3 associated with plastinated specimens, Fig. 1B is for questions 4-6 associated with 3D-printed models whilst Fig. 1C is linked to questions 7-9 associated with human cadaver specimens. The without prior experience- group (Y1) is expressed by the blue bars and orange represents the experienced group (Y3).

Overall, the 3D-printed models were rated to be easiest to locate the anatomical features asked for in the test paper (average Likert scale scores 5.5, 8.0 and 8.3). The supplemental analyse (Supplement 3) in Fig. S1-S2 relate to and confirm the findings above. Fig. S1 gives the P values for the differences in the Likert scores for the material used. As can be seen here, the 3D differed significantly from plastinated and wet ($P=0.0002$, and $P=0.0007$).

The findings above are further explored by looking at by the right and wrong answers obtained for 3D-printed models by both without prior experience and experienced groups (Fig. 2). The differences where statically significant ($P<0.0001$). The graph shows the response to each question associated with 3D-printed models (Q4, Q5, and Q6). The majority of the without prior experience and experienced groups got the right answers (Q4: 87%, Q5: 70% and Q6: 13%) whilst only a few participants got the wrong answers on the 3D-printed models (Q4: 13%, Q5: 30% and Q6: 4%). This indicates the 3D-printed models were found the easiest to use by participants in the identification of the pinned structure.

Participants scored fairly high in Q2 (participants were asked to locate the subscapularis muscle) in the test paper associated with the plastinated specimen of the anterior view of the shoulder (96% got the correct answer and 4% got the incorrect answer). This could be due to the ease of the specimen type in comparison to Q1 of the test paper (participants were asked to locate the pulmonary trunk) associated with the plastinated specimen of the heart. The heart has a peculiar anatomical structure and features that make it more difficult to identify; participants scored 60% correct whilst the remaining scored 39% incorrectly.

Supplemental Fig. S2 compares the scores in terms of the specimens presented in the test questions. This shows there is no significant difference in the overall scores between any of the specimens used in the test.

Supplemental Fig. S3 gives the P values for this comparison for the plastinated material ($P<0.0001$ overall) and also for the shoulder-heart difference. The thigh was also significantly different from the heart ($P=0.0038$).

This result does support the finding that the heart features are more difficult to identify.

There was little difference between the without prior experience and experienced groups (average Likert scale scores 7.3 and 6.7. See Fig. S4 (A-D) which compares them). There is no significant difference between the groups overall, however, there was a significant difference for the wet material ($P=0.0211$).

Post-test survey

The remaining figures relate to the post-test survey, which explored perceptions of assistance given and personal preferences towards the use of the materials.

Fig. 3 displays the different materials (3D, plastinated and human cadaver specimens) that assisted the participants (Q4) the most with identifying and locating the pinned anatomical structures. 74% of participants (both without prior experience and experienced) selected 3D-printed models (3D) as the most effective tool or material for identification of pinned anatomical structures, 17% selected plastinated materials (P) and only 9% of the participants selected human cadavers (HC) or wet specimens. This difference was statistically significant ($P<0.0001$).

Fig.4 displays the proportion of the personal preferences of participants (Q5) (both without prior experience and experienced) of the different materials (3D, human cadaver and plastinated specimens). 45% of the participants preferred 3D-printed models, 36% preferred human cadaver specimens and only 18% of the participants selected plastinated materials as their preferred choice of method of leaning anatomy. The differences were statistically significant ($P<0.0001$).

Fig. 5 compares the total test paper scores for all questions for the without prior experience and experienced participants. Overall both groups did considerably well, 1st year students scoring 67% of the test paper questions right and 3rd year students scoring 88% correct. The differences were statically significant ($P=0.0002$).

Fig. 6 is obtained from post-test survey Q3, asking participants if they had previous exposure to cadaver and/or plastinated anatomy specimens in a university anatomy facility. It is evident from the graph that the majority of participants had previous exposure from both populations; 9 students from the 1st years had previous exposure whereas only 2 students hadn't had any previous exposure, whilst all 12 students in their 3rd year had previous exposure. In this case there is no correlation between previous exposure and student's overall performance.

DISCUSSION

The study results demonstrated that 3D-printed models could be an effective tool in anatomy learning. We probed this new tool in several ways; in terms of ease of use, accuracy, assistance provided to learning, previous experience, and personal preferences.

Ease of use

Ease of use was rated using a Likert scale, (see Fig. 1A) where the 3D-printed questions (Q4-6) were scaled as the easiest (overall) compared to human cadaver and plastinated models by the participants. Looking at the individual questions for each specimen, Q5 and Q8 associated with the 3D-printed heart and wet heart scored the lowest range answers (Fig. 2), which is also reflected in the Likert Scale results (Fig1B); this could be due to the fact that the ease of apprehension of the different models were unequal (see also Fig. S1 in the Supplement 3).

Some of the possible explanations for ease and effectiveness of 3D-printed models compare wet and plastinated materials include the fact that 3D-printed models were in color and the 2D images provided per specimen were also printed in color. The addition of the fully labelled 2D images were provided as the test paper was not testing anatomical knowledge directly, but assessing rather how the participants can contextualize 2D and different 3D specimens for anatomy learning. This aspect could have brought some advantage to participants in the identification of the pinned structures. An example can be represented by blood vessels, veins and nerves shown as red, blue and yellow on the 3D-printed models and as well as the 2D images, whereas these structures are obviously not colored on wet and plastinated specimens. This aspect could be a reason why a greater proportion of participants found 3D-printed models easier to manipulate and assess than wet and plastinated models. As noted, the possibility to customize 3D-printed models with different colors can be useful as well advantageous for the novice student. 3D-printed models can also be printed in a beige color to replicate wet and plastinated specimens (Lim et al, 2016). An earlier study of 3D-printed congenital heart disease further supports this study, finding the participants had significantly better understanding of the disease by using 3D-printed models compared to uncolored models (Ejaz et al., 2014). Another factor to consider is whether 3D models are inherently able to convey more information about an objection to the brain rather than a 2D image, as we see in 3D (depth perception) (Azer and Azer, 2016).

Future investigations will need to focus on the question whether the handling and interaction with different specimen materials improves anatomical learning of the students.

A potential bias given by student's personal interest in the field could highlight the different perspectives towards different anatomical materials (3D, wet and plastinated) between students and thus influence learning experience and outcomes.

Accuracy

Fig. 2 highlights the accuracy of students in identifying the requested features in 3D-printed specimens. Data is representative for the whole cohort, including both without prior experience and experienced students. We grouped the study population together owing to hardly any difference between the two groups (see Fig. 3).

Assistance to learning process

Fig.3 suggests that in our small cohort the specimens that were most useful in identifying the requested anatomical structures were the 3D-printed materials: nevertheless any firm conclusion is risky, given the small size of our study population as well as the bias represented by the colors of the specimens and also the intrinsic differences in the various questions.

Personal preferences

Our students prefer handling 3D-printed models over wet cadaver materials as students found it more comfortable using and handling 3D-printed models in compassion to wet specimens. This is anecdotal feedback provided by participants after the conduction of the study. Despite being not assessed in the study, this concept is supported by literature where 3D-printed models were regarded as a useful tool in facilitating comfort and preventing psychological inhibitions in order to stimulate the use of 3D-printed models (Lim et. Al., 2016). Handling of wet specimens requires caution because of the exposure to formalin containing embalming fluids, whereas there is less risk associated with the handling of 3D-printed models as they do not contain harmful chemicals. The larger number of participants (74%) who preferred 3D-printed models compared to wet and plastinated models could be due to the safety issues regarding the use of wet and plastinated models described above. 3D- printed material can represent in fact a substantial advantage in handling and examining as a first "anatomy encounter" for undergraduate students.

Overall Performance and Previous Exposure

There is no significant difference between overall performances of both populations (Fig. 5) as most participants had previous exposure in a university anatomy facility previous to the study (Fig. 6). Another reason as to why there is no correlation between overall performance and previous exposure could be due to the fact the study was set for voluntary participation. I.e. only "interested" students would have taken part. Very few students had no previous exposure (Fig. 6) which could only be a factor in considering the other results gathered from the study such as the ease of use and students' overall performance.

Limitations

Our study has several limitations. The small amount of participants could have been due to the study being completely voluntary, which could have attracted participants particularly interested in anatomy as a discipline. Workload of the study population during academic semester 2 is another strong factor that hampered our recruitment effort. Furthermore, the study population consisted of a without prior experiencegroup and an experienced group of participants with substantial differences in cadaveric material exposure. There is a possibly remarkable difference in the anatomical knowledge of the two groups and it could have been relatively easier for third year students (experienced) to identify the pinned structure compared to first year students (without prior experience). The study could further be improved by having a larger number of participants and two homogenous groups. For example, having first year 1st semester HSF students as the without prior experience- group and first year 2nd semester Integrated Systems of Anatomy and Physiology (ISAP) students as the experienced group. A study with a larger number of participants and two homogenous groups might have given different results. Therefore, future studies need to investigate whether the outcome is altered when having different cohorts.

Another limitation of this study is that it lacks demographic details such as age and sex, which could be a factor in altering the study outcomes because different sexes (male and female) and ages have different interpretations. For example, mature ages are more hands-on with real and original materials whereas the younger generation are educated in a technology based environment. Future investigations will assess the contribution of sex and age on the preference of anatomical specimen use. Finally, it is important to address the potential limitations of the technology itself; despite the high quality of the 3D specimens, they differ substantially in weight, colour, texture, tactile and other properties compared to cadaveric material. These differences can vary depending on the quality of CT scans used for their production (Lim et al., 2016).

Despite these limitations, our results fit and complement recently published data (Lim et al 2016, Smith et al 2018, Mogali et al 2018, and Chen et al 2017) that show a favorable attitude towards 3D-printed specimens. Pre-tests and post-tests by Smith et al (2018) demonstrated that 3D-printed anatomical specimens can be used as an effective teaching aid that help an objective increase in student learning and knowledge. Our results support the work of Lim et al and (2016) and Chen et al (2017) that found significant effect in small randomized control trials in the group who used 3D-printed specimens.

Future trends/Research/Applications

The cost of manufacturing 3D-printed models is high but seems to be reducing and it is convenient in regards to the consent related to a plastinated model (McMenamin et al, 2014). Moreover, 3D-printed models miss some physical characteristics from cadaver specimens such as texture, colour and tactile properties. These differences can vary depending on the quality of CT scans used for their production (Lim et al., 2016).

As we have investigated the ease of use, accuracy and personal preference of 3D-printed models in conjunction with traditional specimen types (plastinated and cadaver specimens) future investigation around the topic of 3D-printed models could include the following ideas which have been raised throughout the study. Assessing if sex and age has any effect on the use of different specimen materials (3D, plastinated and wet) as well as investigating ifmotivation and interest in learning anatomy alters study outcomes. A larger number pf participants is an important aspect for future investigations as well as comparison with other materials, i.e. could plastinated specimens be superior to 3D-printed models for certain types of sections of the body due to complexity of the human body.

Conclusions

3D printing is a modern technique able to provide valuable 3D-printed anatomical models for anatomy learning. The study findings suggest that 3D-printed models have the potential to assist students in anatomy learning and have the capability to be used adjacent to human cadaver materials, in agreement with recent literature and possibly in an integrated way with existing tools. The use of 3D-printed models brings benefits not only to anatomy students but also the lecturer, limiting the amount of time spent for teaching, running of the laboratory sessions and helping with the decreasing amount of anatomy staff. 3D-printed models also can be used within the wider community by enhancing patient specific/personalized treatment. 3D-printed models are easy to store and preserve unlike human cadaver specimens, they can also be tailored to be produced in different colors and sizes as well as they give the ability to have several identical prints which can be used in a classroom setting at once.

The use of 3D-printed models in anatomy education deserves attention in the modern anatomy pedagogy with the likely lowering of price manufacturing and improved techniques in the near future. As there are numerous problems associated with the use of traditional anatomy learning methods, 3D-printed specimens as a high quality teaching tool can definitely alleviate the ethical, cultural, logistical and financial difficulties of maintaining a cadaver-based curriculum and, at the same time align with the newest concepts in anatomy education.

ACKNOWLEDGEMENTS

M.V. thanks Prof. William Hart (Dean, Curtin Medical School) for support, encouragement and useful discussion and the team of the Anatomy Facility at the School of Pharmacy and

Biomedical Sciences at Curtin University for excellent assistance in carrying out this study (in particular Melissa Parkinson, BS, John Warwick, BS and Alana Stainton, BS)

FUNDING

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of interest: the authors declare no conflict of interest.

REFERENCES

Azer SA, Azer S. 3D Anatomy Models and Impact on Learning: A Review of the Quality of the Literature. Health Professions Education 2016, 2(2), 80-98.

Bergman EM., 2015. Discussing dissection in anatomy education. Perspect Med Educ, 4:211-213. doi 10.1007?s40037-015-0207-7 MAURO

Bergman EM, Prince KJ, Drukker J, van der Vleuten CP, Scherpbier AJ., 2008. How much anatomy is enough? Anat Sci Educ.;1(4):184-8. doi: 10.1002/ase.35.

Chan LK, Pawlina W (Eds) 2015.Teaching Anatomy. A Practical Guide. Springer International New York , NY,

Chen S, Pan Z, Wu Y, Gu Z, Li M, Liang Z, Zhu H, Yao Y, Shui W, Shen Z, Zhao J, Pan H., 2017. The role of three-dimensional printed models of skull in anatomy education: a randomized controlled trial. Sci Rep. 7(1):575. doi:10.1038/s41598-017-00647-1.

Ejaz F, Ryan J, Henriksen M, Stomski L, Feith M, Osborn M, Pophal S, Richardson R, Frakes D. 2014. Color-coded patient-specific physical models of congenital heart disease. Rapid Prototyping J 20:336–343.

Estai M, Bunt S., 2016. Best teaching practices in anatomy education: A critical review. Ann Anat. 208:151-157. doi: 10.1016/j.aanat.2016.02.010. Epub 2016 Mar 17.

Ghosh SK. 2017. Cadaveric dissection as an educational tool for anatomical sciences in the 21st century. Anat Sci Educ. 2017; 10(3):286-299.

Lim KH, Loo ZY, Goldie SJ, Adams JW, McMenamin PG., 2016. 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(3):213-21. doi: 10.1002/ase.1573. Epub 2015 Oct 15.

Losco CD, Grant WD, Armson A, Meyer AJ, Walker BF. 2017 Effective methods of teaching and learning in anatomy as a basic science: A BEME systematic review: BEME guide no. 44. Med Teach. 39(3):234-243. doi: 10.1080/0142159X.2016.1271944. Epub 2017 Jan 27.

Louw G, Eizenberg N, Carmichael SW., 2009. The place of anatomy in medical education: AMEE Guide no 41, Medical Teacher. vol. 31, no. 5, pp. 373–386.

McBride JM, Drake RL. National survey on anatomical sciences in medical education. Anat Sci Educ. 2018 Jan;11(1):7-14. doi: 10.1002/ase.1760. Epub 2017 Dec 19.

McLachlan JC, Bligh J, Bradley P, Searle J., 2004 Teaching anatomy without cadavers. Med Educ.38:418-24.

McMenamin PG, Quayle MR, McHenry CR, Adams JW.,2014. The production of anatomical teaching resources using three-dimensional (3D) printing technology. Anat Sci Educ 7:479–486.

Mogali SR, Yeong WY, Tan HKJ, Tan GJS, Abrahams PH, Zary N, Low-Beer N, Ferenczi MA., 2018. Evaluation by medical students of the educational value of multi-material and multi-colored three-dimensional printed models of the upper limb for anatomical education. Anat Sci Educ.11(1): 54-64. doi: 10.1002/ase.1703. [Epub ahead of print 2017 May 19.]

Older J., 2004. Anatomy: a must for teaching the next generation. Surgeon 2(2):79-90

Papa V, Vaccarezza M., 2013. Teaching anatomy in the XXI century: new aspects and pitfalls. ScientificWorldJournal 310348. doi:10.1155/2013/310348.

Patel KM, Moxham BJ., 2008. The relationships between learning outcomes and methods of teaching anatomy as perceived by professional anatomists. Clin Anat. 21(2):182-9. doi: 10.1002/ca.20584.

Pawlina W, Drake RL., 2016. Authentic learning in anatomy: A primer on pragmatism. Anat Sci Educ. 9(1):5-7. doi: 10.1002/ase.1592.

Smith CF, Tollemache N, Covill D, Johnston M. 2018 Take away body parts! An investigation into the use of 3D-printed anatomical models in undergraduate anatomy education. Anat Sci Educ. 11(1): 44-53. doi: 10.1002/ase.1718. [Epub ahead of print 2017 Jul 28]

Sugand K, Abrahams P, Khurana A., 2010. The anatomy of anatomy: a review for its modernization. Anat Sci Educ. Mar-Apr;3(2):83-93. doi: 10.1002/ase.139.

Vaccarezza M., 2018. Best evidence of anatomy education? Insights from the most recent literature. Anat Sci Educ.11(2) : 215-6 doi: 10.1002/ase.1740. [Epub ahead of print 2017 Sep 22]

Vaccarezza M, Papa V., 2015. 3D printing: a valuable resource in human anatomy education. Anat Sci Int. 90(1):64-5. doi: 10.1007/s12565-014-0257-7. Epub 2014 Oct 7.

Wilson AB, Miller CH, Klein BA, Taylor MA, Goodwin M, Boyle EK, Brown K, Hoppe C, Lazarus M. 2018 A meta-analysis of anatomy laboratory pedagogies. Clin Anat.31(1) : 122-33 doi: 10.1002/ca.22934. [Epub ahead of print 2017 Jun 13]

Winkelmann A. 2007 Anatomical dissection as a teaching method in medical school: a review of the evidence. Med Educ., 41: 15-22

Fig 1A. Likert scale average. Questions 1-3 of the test paper associated with plastinated specimens. (P-Value = 0.1097).

Fig 1B. Likert scale average. Questions 4-6 of the test paper associated with 3D-printed specimens. (P-Value = 0.8652).

Fig 1C. Likert scale average. Questions 7-9 of the test paper associated with cadaver specimens.(P-Value = 0.0211).

Fig 2. Proportion of right and wrong answers for 3D-printed models (Questions 4-6 in test paper) (P-Value = <.0001).

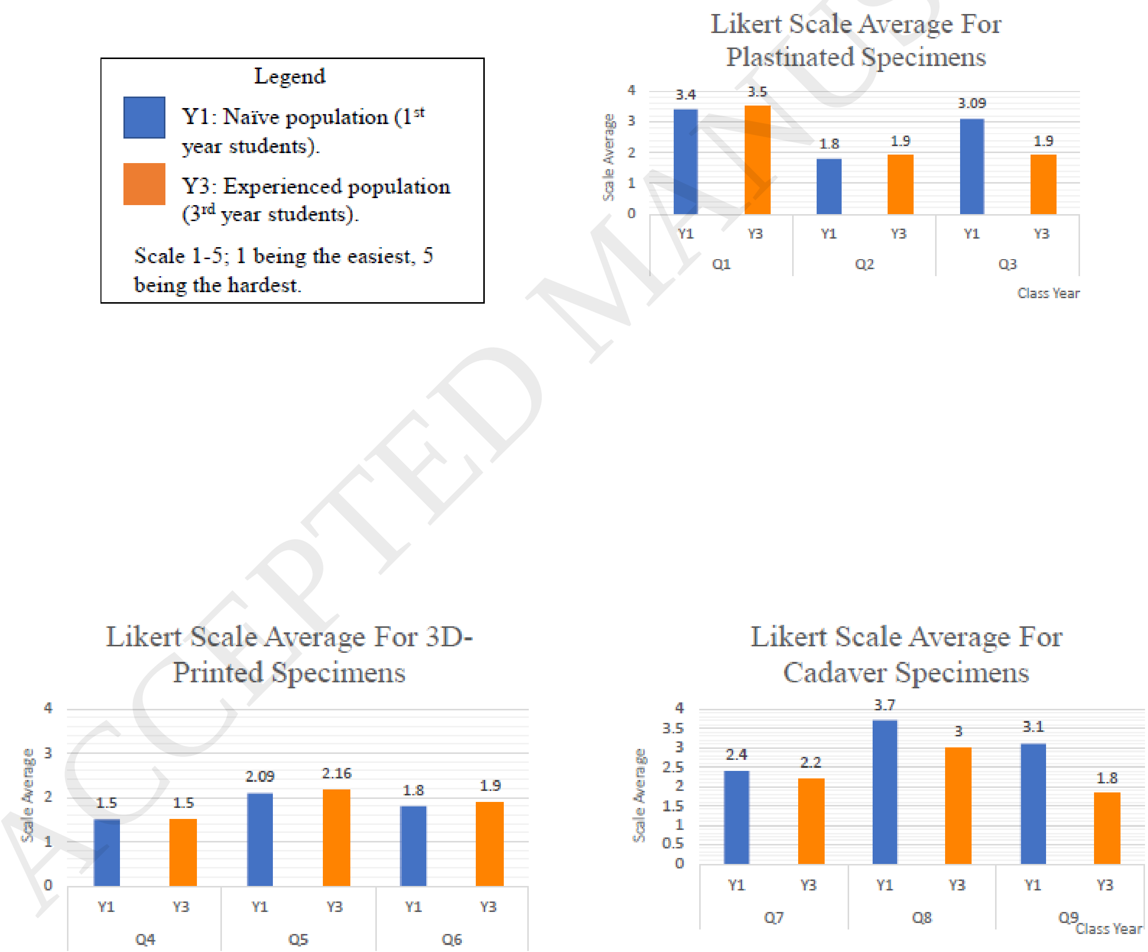
Fig 3. Proportion of different specimen materials that assisted participants the most with the identification of pinned structures. 3D: 3D printed specimen; HC: Human cadaveric specimen; P: Plastinated specimen. (P-Value <.0001)

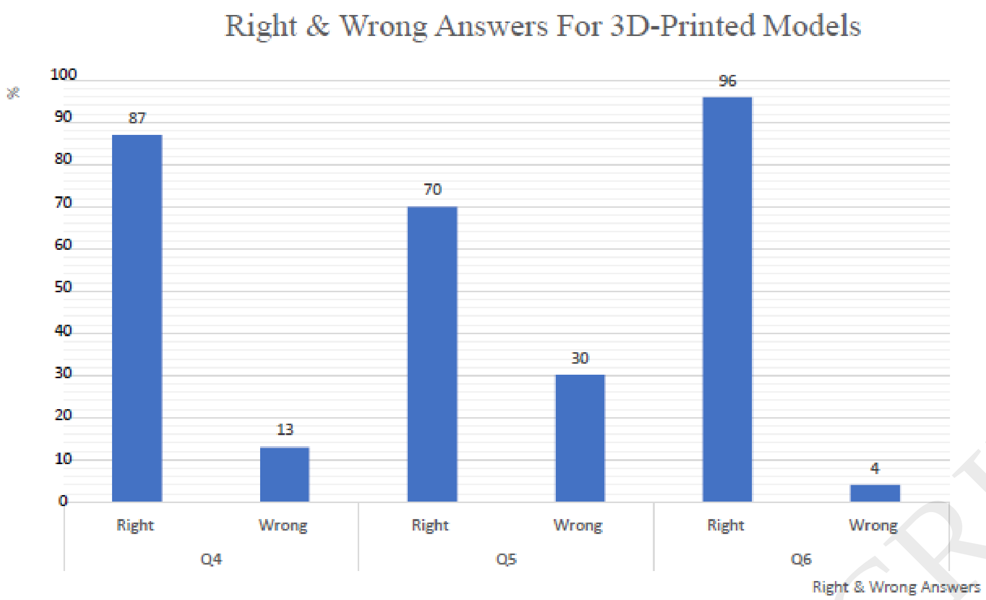
Fig 4. Proportion of specimen materials based on personal preferences of participants

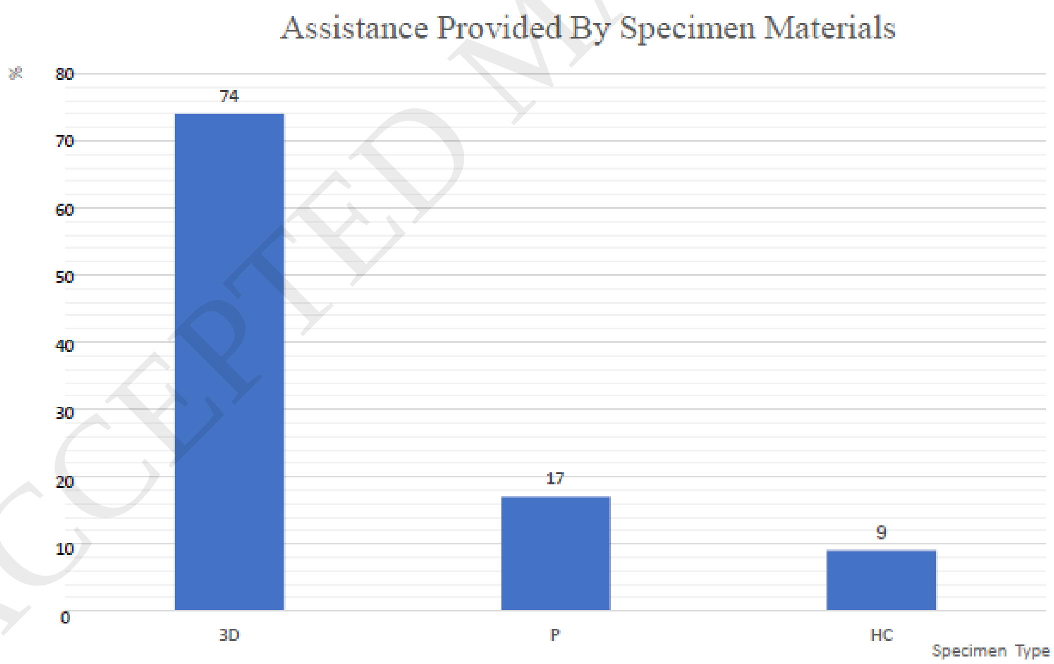
(P-Value <.0001).

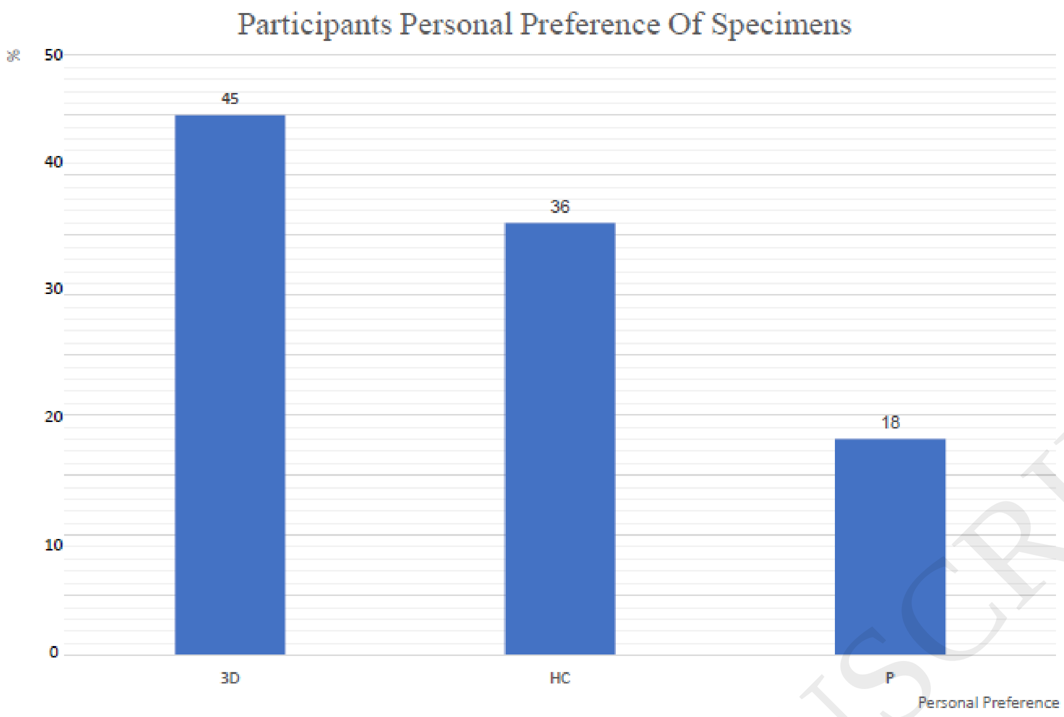
Fig 5. Participant's performance. Proportion of Right and Wrong Responses From The Test Paper.

Fig 6. Number of participants previously exposed to human tissues or not.




Right & Wrong Answers For 3D-Printed Models
%
100
90
80
70
60
50
40
30
20
10
0
87
13
70
30
96
4
Right
Wrong
Right
Wrong
Right
Wrong
Q4
Q5
Q6
Right & Wrong Answers


Assistance Provided By Specimen Materials
%
80
70
60
50
40
30
20
10
0
74
17
9
3D
P
HC
Specimen Type


Participants Personal Preference Of Specimens
%
50
40
30
20
10
0
45
36
18
3D
HC
P
Personal Preference


Participant's Performance Over All
Right
Wrong
%
100
90
80
70
60
50
40
30
20
10
0
67
33
88
12
Y1
Y3
Class Year


No Exposure VS Previous Exposure
YES: Previous Exposure
NO: No Previous Exposure
Number Of Participants
14
12
10
8
6
4
2
0
YES
NO
Y1
YES
NO
Y3
Class Year