Use of a virtual 3D anterolateral thigh model in medical education: Augmentation and not replacement of traditional teaching?

Steven Lo [1,2,3], Abdul Shakor Sandel Abaker [4], Fabio Quondamatteo [5], Jenny Clancy [5], Paul Rea [5], Michael Marriott [4], Paul Chapman [4]

1) Canniesburn Plastic Surgery Unit, Glasgow Royal Infirmary

2) College of Medical, Veterinary and Life Sciences, University of Glasgow

3) Translational Research Centre, Kaohsiung Medical University

4) School of Simulation and Visualisation, Glasgow School of Art

5) Laboratory of Human Anatomy, University of Glasgow

Corresponding Author:

Steven Lo

Canniesburn Regional Plastic Surgery and Burns Unit

Glasgow Royal Infirmary

Glasgow, G4 0SF

Tel: 07447 047233

stevenjlo@gmail.com

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Abstract

There is a pressing need for simulated forms of medical - and in particular - anatomical learning. Current modalities of teaching are limited to either traditional 2 dimensional forms of learning such as textbook, research papers, and lectures, or more costly 3 dimensional modes including cadaveric dissection. Despite the overwhelmingly 3 dimensional nature of Plastic Surgery - virtual 3D models are limited. Here we provide the first description of the development and utilisation of a virtual 3D flap model in medical education in the Undergraduate Curriculum.

Methods and Results

A 3D anterolateral (ALT) model was developed with close integration of specialists in simulation and visualisation, anatomists and clinicians, allowing 'virtual dissection' of the anatomy of the ALT flap. This was utilised on a BSc Anatomy undergraduate course in 2017/18 and 2018/19. Student feedback noted an overwhelming preference for the 3D model (74%) as first choice of educational methodology, versus lectures (26%), textbooks (0%) and research papers (0%) ($p=0.0035$). Extraneous cognitive load may be reduced with 3D models, with students rating these easier to learn from than textbook or research papers ($p=0.00014$ and $p<0.00001$ respectively). Notably, no statistically significant difference was found in perceived ease of learning between 3D models and lectures.

Conclusions

This study highlights a striking user preference for virtual 3D models over traditional teaching methods. Nonetheless, 3D models are likely to enhance rather than replace

lectures, with this study suggesting that teaching by experts is likely to remain an essential part of medical education.

Introduction

There is a pressing need for simulated forms of medical - and in particular - anatomical learning. Reduced working hours in Europe, the USA and other countries has impacted upon the apprenticeship model of “see one, do one, teach one”. Current modalities of teaching are limited to either traditional 2 dimensional forms of learning such as textbook, research papers, websites and lectures, or more costly 3 dimensional modes including cadaveric dissection. Despite the overwhelmingly 3 dimensional nature of learning and eventual practice in Plastic Surgery - virtual 3D models are limited. We are unaware of other custom virtual simulated 3D flap models used routinely in medical education, although there are numerous reports on the use of patient specific renderings from CT data [1,2,3] and saturation in the global market with 3D anatomical products such as Anatomy TV, Zygote and others [4,5] Likewise, in recent years there has been vertiginous development of augmented and virtual reality in diverse fields including veterinary anatomy, neuronatomy, cardiovascular, maxillofacial surgery, dental medicine and others [6-9].

Close integration of specialists in simulation and visualisation, anatomists and clinicians is needed to allow the development of real-world applicable models for learning. In this regard, a real time virtual 3D model anterolateral thigh (ALT) model has been developed to help meet the educational needs in Plastic surgery. Initially conceptualized in 2015/16 during a postgraduate Masters project [10] in the School of Simulation and Visualisation, Glasgow School of Art, in conjunction with anatomy staff of the School of Life Sciences, University of Glasgow, and clinicians from the

Canniesburn Plastic Surgery Unit, this has now been separately developed into a suitable model for medical education. This has now been employed for the last 2 years to enhance the learning experience in a BSc Undergraduate Anatomy course at the University of Glasgow. This study aimed to provide an overview of the development process, implementation and evaluation of the virtual 3D ALT model as a teaching asset in the undergraduate curriculum.

Methods and Results

Model development

The current model was developed by the senior author (SL) in conjunction with the School of Simulation and Visualisation, Glasgow School of Art, using the professional modelling software Autodesk 3DS max (Autodesk, Inc., California USA) used by design studios worldwide such as Pixar Animation, together with a combination of opensource (Bodyparts3D, Research Organization of Information and Systems Database Center for Life Science, Japan) and custom developed models. A low polygon count base model was used for the thigh, allowing the model to run without significant lag **(Figure 1).** Two separate ALT models were created – a low polygon model to run with the thigh model during 'virtual dissection', and a higher polygon, more detailed model to be run as a standalone version. The vascular anatomy, including the lateral circumflex descending artery, transverse branch, branch to rectus femoris, oblique branch, and two perforators, was individually modelled and labelled. The thigh and constituents were rendered in artificial colours to highlight the differential anatomy. Subsequent rendering of the ALT model was done with photomapping of authentic tissue textures, and with lighting rigs that mimic intra-operative lighting, creating a life-like appearance **(Figure 2, 3 and 4).**

Model User Interface

This model allows real time movement of the model in 3D space, virtual 'dissection' by removal of individual anatomical components eg rectus femoris muscle, ‘skeletalization’ of the flap to show the detailed perforator anatomy in isolation,and movement of the ALT flap into and out of the thigh. As the individual components of the vascular system are labelled and separately modelled, the student can identify the various branches of the lateral circumflex artery with ease. Furthermore, difficult 3D concepts such as the key intermuscular plane between rectus femoris (RF) and vastus lateralis (VL), which is hard to visualise using a 2D textbook, is easy to demonstrate with the 3D model by rotating the model and separating the RF from the VL **(see supplementary video).** At present the model is used in Autodesk 3DS max, with plans to adapt it to a custom user interface with additional interactive functionality such as a “question and answer” facility that will aid the learning experience.

Use of the 3D ALT model in the Undergraduate Anatomy Curriculum

Approval was obtained from the Head of Department, Laboratory of Human Anatomy (FQ) to use 3D models as an integral part of the BSc Anatomy courses 2017-18 and 2018-19 taught by the authors (JC and SL), with separate ethical approval not required according to the regulations of the College of Medicine, Vetinary and Life Sciences, University of Glasgow for studies based on course evaluation feedback. In the last 2 years this has been utilised by a total of 52 Final Year undergraduate BSc students in Anatomy at the University of Glasgow in the context of a lower limb specialist teaching module, and evaluated in the first year of its use as part of routine course feedback and for quality assurance purposes. This course takes Plastic surgery naïve students through the complexities of raising the ALT flap, with the 3D model comparing favourably to other modalities including textbooks, research papers, and lectures on the ALT flap. All non-cadaveric based teaching was completed in one afternoon at the School of Simulation and Visualisation, Glasgow School of Art. A reading list with required textbooks and seminal research papers on the ALT flap was mailed to students at the start of the lower limb specialist module block. Three lectures were given by Plastic Surgery and Radiology Consultants covering the specialist anatomy, imaging and clinical use of the ALT over 1.5 hours. The traditional teaching aspects of the course were not altered in any way to accommodate the virtual 3D models. Navigation and “virtual dissection” of the 3D ALT model was demonstrated by the authors (MM and SL), followed by self-practice at individual student workstations with feedback as required, for 1.5 hours **(Figure 5).** On a separate day, practical knowledge gained through this teaching day was used in a cadaveric session at the Laboratory of Human Anatomy, Unviersity of Glasgow, where the students dissected the ALT flap. This provided a *reference frame* for students regarding the accuracy of the teaching methods that they have been exposed to i.e. *“how do I know what I have learnt is accurate in comparison to an actual human body”.*

Course Evaluation

Course evaluation and qualitative feedback were completed by 19 out of 21 students in 2017/18. Statistical analysis was performed with SPSS (IBM SPSS Statistics for Windows, Version 24.0. Armonk, NY: IBM Corp), with Chi Square Goodness of fit and post hoc Z test with SocSciStatistics [11]. Course evaluation indicated a strong educational preference for the virtual 3D model (74% rated this educational modality as their first choice) over traditional forms of teaching including lectures (26%), papers (0%) and textbooks (0%) (Graph 1). This suggests that 3D models, although strongly preferred as a teaching method (p=0.0035), may require contextualization by an expert in the form of lectures. (Null hypothesis: preferences amongst the teaching modalities would be equal at 25%. Chi Square Goodness of fit = p<0.001 indicating significant differences between preferences for each group. Post hoc Z test of proportions of 3D models versus lectures p=0.0035). The cadaveric dissection itself was not used as a separate evaluation factor, as our aims were to assess how classroom based teaching methods compare as *aids to dissection (for example, is virtual dissection helpful for real dissection?)*. In a similar manner, this type of evaluation will be used in our future research to rate different teaching methods as an *aid to surgical practice (for example, is surgical simulation helpful for real surgery?)*.

Students rated the ease with which the complex anatomy of the ALT flap was conveyed. Although this study was not designed to formally assess cognitive loads on students, 'ease of learning' feedback ratings give an indication of cognitive load (see Discussion). This was considered best with the 3D models (58% easy, 42% moderate, 0% difficult), followed by lectures (53% easy, 47% moderate, 0% difficult), textbooks (0% easy, 74% moderate, 26% difficult) and research papers (11% easy, 5% moderate, 84% difficult) (Graph 2). Kruskal-Wallis test on the ranked data was significant (p<0.0001). Median rank for the 3D models was 'easy', lectures 'easy', textbooks 'moderate' and research papers 'difficult'. Post hoc analysis with Mann-Whitney U showed no difference between 3D models and lectures (p=1.00), but significant differences between 3D models and textbooks (p=0.00014) and research papers (p<0.00001) (with Bonferonni corrected significance at p=0.017).

Thematic analysis of qualitative feedback

Assessment of qualitative student feedback indicated the following recurrent themes:

The virtual 3D models clarified spatial awareness and were 'repeatable'

Students noted that although lectures on the ALT flap were relatively complex and fast paced, difficult anatomy concepts became clearer when students were able to visualise this on the computer. Students used words including "excellent", "visualise", "very useful", "accurate" and "clear" in reference to the virtual models. They also felt that when they did something wrong during 3D model dissection it did not matter, as they could repeat the process, unlike during cadaveric dissection where for example, a cut perforator could not be reversed. Spatial anatomy was a particular advantage of the 3D models, as elements could be removed sequentially to see the underlying anatomy. This was noted to be a significant advantage over textbooks and plastinated prosections. Suggested improvements in the 3D model were to incorporate a didactic element such as a "question and answer" facility.

Traditional teaching methods, particularly lectures, were still endorsed

Although students perceived significant advantages with the 3D model, lectures were still appreciated and in particular they felt that the enthusiasm of the lecturers often made the teaching more memorable. Most students consistently used words such as "liked", "enjoyed","enthusiasm" and "encouraging" when referring to lectures. However they had drawbacks including complexity of material, information overload, and quality of lecture can vary according to lecturer and topic. The textbooks and research papers were less enthusiastically endorsed, with the concern that they can be prone to misinterpretation without an educator to explain more difficult concepts. On the positive side, it was felt that they allowed more in-depth further study once the basics had been grasped. Together this qualitative feedback pointed towards 3D models being complimentary to traditional methods, and collectively they can enhance the learning experience.

Discussion

This is the first study to detail the development and use of a 3D virtual flap model in the undergraduate curriculum, and highlights a striking user preference for this over traditional teaching methods, with nearly three quarters of students considering this their first choice. Although this serves to highlight that there is significant enthusiasm for new, simulative technologies, this does not necessarily obviate the role of traditional teaching methods, as we discuss later.

Currently although there is a surfeit of 3D anatomical products on the global market, niche specialties such as Plastic Surgery do not garner the same attention as the general anatomical curricula, with no commercially available 3D virtual plastic surgery flap models on the market at the time of writing. This is in part due to the enormous funding, time, and specialist expertise required to generate and validate such products, with the Definitive Human[12] developed by our team at the School of Simulation and Visualisation, Glasgow School of Art, and the Laboratory of Human Anatomy, University of Glasgow, costing in excess of a million pounds. It is hoped that the present study - indicating that there is utility, benefit and passion for 3D flap models in medical education - can help spur investment and development in the specialist and somewhat neglected field of Plastic Surgery.

Although some may consider that currently available 3D anatomical models such as Anatomy TV are suitable for the teaching of Plastic Surgery or flap raising, they are designed primarily for medical student education and schooling in gross anatomy [4]. As such, they often lack the specific, detailed and relevant vascular anatomy distinct to the raising of flaps, with perforator anatomy such as that pertaining the lateral circumflex system often poorly represented, misrepresented or absent in its entirety. Moreover, rendering - the process of creating the real-time on screen appearance of a 3D model - is often inaccurate and unrealistic, with a bias towards cadaveric or plastic textures. We have addressed these problems with the current ALT model, and aim to likewise provide a compendium of similar anatomically relevant, photorealistic flaps, developed by an integrated team of simulation and visualisation experts, anatomists and Plastic surgery clinicians. In addition, future applications will improve the user experience by employing a custom user interface that does not require specialist software, thus allowing a more intuitive and finessed virtual 'dissection'. An interactive component, a feature favoured by students when asked about areas for improvement, will be taken into account in future versions of the 3D flap model with incorporation of "question and answer", short case video, and tutorial functionalities. It is hoped that our interspeciality collaboration, based on the state-of-the-art Definitive Human 3D model [12] in conjunction with custom created flap models, plus integration with haptics, virtual and augmented reality systems, will provide a landmark plastic surgery education tool.

However despite the appetite for virtual and augmented reality models, empirical evidence supporting current technologies is limited, with studies suggesting that further development and educational validation are required [7,8]. Recent data casts some doubt on improved anatomical knowledge with the use of a neuroanatomical augmented reality application in comparison to traditional teaching methods, but does suggest that such applications can reduce the extraneous cognitive load on students. In simple terms, this means that visualisation technologies may make inherently difficult topics (the intrinsic cognitive load) easier to understand and process (7). Our study, although limited to student evaluation and feedback only, presents one of the few attempts to assess 3D virtual technology that is used as an integral part of the undergraduate curriculum, and not as a separate trial. The data presented here suggests a strong preference for 3D virtual models with 74% of students preferring this as their first choice of educational modality (p=0.0035). Lectures retained a significant minority preference (26%), but no student chose textbooks or research papers as their first choice. Despite the inclination for the 3D models, the actual ease of learning was equivalent between 3D models and lectures (58% versus 53% rated as “easy”, p=1.00), and significantly better with 3D models than textbooks (p=0.00014) or research papers (p<0.00001). Therefore, although this study was not designed to assess cognitive loads on students, one can infer from these data that 3D models may reduce extraneous cognitive load in comparison to textbooks and research papers. Further studies will incorporate validated forms of cognitive load assessment such as the Mental Effort Rating Scale [13]. Qualitative feedback suggested an enthusiastic adoption of 3D technologies - in particular with a perceived enhancement in spatial learning and scope for repeatable practice dissection – but lectures were also viewed favourably and are likely to remain a core component of the curriculum. Nonetheless, as these technologies are in the ‘early adopters’/ ‘early majority’ phase of the technological life cycle [14], it is expected that unlike with lecturers, there is scope for rapid, feedback-based, iterative improvement in 3D models. Therefore the disparity between 3D models and traditional forms of learning, in particular lectures, is likely to grow rather than shrink. We hope to address some of these issues in the near future with an improved model, and with subsequent evaluation using robust, validated forms of quantitative and qualitative pedagogical assessment.

Lastly, it is of some comfort for clinicians and educators to note that 3D models are likely to enhance rather than replace lecture based teaching by experts. A significant proportion of tech savvy undergraduate students still feel that lectures are one of the best approaches to instil complex anatomy, with no significant difference in ease of learning with lectures versus the current version of this 3D model. This suggests that the role of AR is supplementary to and not mutually exclusive with traditional approaches. However, we expect that with improvements gleaned from and tailored to the student feedback in this study, version 2.0 of the 3D model may move some forms of traditional teaching closer to obsolescence, perhaps with the exception of lectures. Nonetheless, at the present time 3D models cannot yet replace some of the essential human traits evident in lectures – the ability to inspire, to enthuse, to edify, and sometimes, to humour.

Isaac Asimov predicted that robots would one day take over the world, making *"humanity obsolete and relegating us to the position of pets, if we are lucky"* [15]. Not yet though, it still seems that the world needs anatomists and surgeons.

Conflict of Interest Statement

None

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Figure Legends

Figure 1:

Thigh model with ALT flap rendered in artifical colours to aid component recognition

Figure 2:

3D model with rendering of ALT flap with rectus femoris muscle

Figure 3:

3D ALT model rotated

Figure 4:

Reverse view of 3D ALT model, with vascular system rendered in artifical colours

Figure 5:

A. 3D model with all muscles in-situ B. Removal of sartorius and rectus femoris. In this model the oblique branch is septocutaneous whilst two further perforators are musculocutaneous passing through vastus lateralis (coloured green) C. Removal of all muscle components showing lateral descending circumflex system with separate components shaded different colours.

Graph 1: Students' educational Preferences

Graph 2: Rating the 'ease of learning' anatomy with different teaching modalities

Supplementary Video: Animation of the model with the rectus femoris and flap being 'removed' whilst the model rotates

References

1. Zhang YZ, Li YB, Jiang YH, et al. Three-dimensional reconstructive methods in the visualization of anterolateral thigh flap. 1, Feb 2008, Surg Radiol Anat., Vol. 30, pp. 77-81.

2. Zhang YZ, Li YB, Tang ML, et al. Application of three-dimensional digitalized reconstruction of an anterolateral thigh flap and an arterial dorsalis pedis flap. 6, 2007, Microsurgery, Vol. 27, pp. 553-9.

3. Lobb DC, Cottler P, Dart D, et al. The Use of Patient-Specific Three-Dimensional Printed Surgical Models Enhances Plastic Surgery Resident Education in Craniofacial Surgery. 2, 2019, J Craniofac Surg, Vol. 30, pp. 339-341.

4 https://www.anatomy.tv. [Accessed: July 27th, 2019.]

5. https://www.zygote.com. [Accessed: July 27th, 2019.]

6. Christ R, Guevar J, Poyade M, et al. Proof of concept of a workflow methodology for the creation of basic canine head anatomy veterinary education tool using augmented reality. 4, 2018, PLoS One, Vol. 13, p. e0195866.

7. Henssen D J H A, van den Heuvel L, De Jong G, et al. Neuroanatomy Learning: Augmented Reality vs. Cross-Sections. . July 3, 2019, Anat Sci Educ., p. doi: 10.1002/ase.1912. [Epub ahead of print] .

8. Joda T, Gallucci GO, Wismeijer D, et al. Augmented and virtual reality in dental medicine: A systematic review. . 2019 , Comput Biol Med. , Vol. 108, pp. 93-100.

9. Bosc R, Fitoussi A, Hersant B, et al. Intraoperative augmented reality with heads-up displays in maxillofacial surgery: a systematic review of the literature and a classification of relevant technologies. . 1, 2019, Int J Oral Maxillofac Surg., Vol. 48, pp. 132-139.

10. Abaker, Abdul Shakor Sandel. A 3D model of the Anterolateral Thigh. School of Simulation and Visualisation, Glasgow School of Art. 2016. Masters Thesis.

11. https://www.socscistatistics.com/tests/ztest/default2.aspx. [Accessed: July 27th, 2019.]

12. http://www.gsa.ac.uk/research/research-centres/school-of-simulation-and-visualisation/research/current-projects/3d-definitive-human/, [Accessed: July 27th, 2019.]

13. Paas, F. G. Training strategies for attaining transfer of problem-solving skill in statistics: A cognitive-load approach. 1992, Journal of Educational Psychology, Vol. 84, pp. 429-434.

14. Rogers, Everett. Diffusion of Innovations. 5th Edition. Simon and Schuster, 2003. ISBN 978-0-7432-5823-4.

15. http://www.asimovonline.com/oldsite/Essays/intelligence.html [Accessed: July 27th, 2019] Essay “Our Intelligent Tools” October 1977 issue of American Way, In-flight magazine of American Airlines.