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Virtual Reality Anatomy: Is it Comparable with Traditional Methods in the Teaching of Human Forearm Musculoskeletal Anatomy?

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The use of cadavers to teach anatomy is well established, but limitations with this approach have led to the introduction of alternative teaching methods. One such method is the use of three-dimensional virtual reality computer models. An interactive, three-dimensional computer model of human forearm anterior compartment musculoskeletal anatomy was produced using the open source 3D imaging program "Blender." The aim was to evaluate the use of 3D virtual reality when compared with traditional anatomy teaching methods. Three groups were identified from the University of Manchester second year Human Anatomy Research Skills Module class: a "control" group (no prior knowledge of forearm anatomy), a "traditional methods" group (taught using dissection and textbooks), and a "model" group (taught solely using e-resource). The groups were assessed on anatomy of the forearm by a ten question practical examination. ANOVA analysis showed the model group mean test score to be significantly higher than the control group (mean 7.25 vs. 1.46, $P < 0.001$) and not significantly different to the traditional methods group (mean 6.87, $P > 0.5$). Feedback from all users of the e-resource was positive. Virtual reality anatomy learning can be used to compliment traditional teaching methods effectively. Anat Sci Educ 4:119–125. © 2011 American Association of Anatomists.

Key words: e-learning; anatomy; teaching; dissection; gross anatomy education; virtual reality; 3D models; computer-assisted learning; CAL

INTRODUCTION

Currently, anatomical study for students in most institutions of higher education is carried out through a combination of didactic lectures, self-directed study with textbooks, and practical laboratory sessions where dissection and observation of cadaveric material can be undertaken. The resources available for anatomy education are being expanded though greater use of living anatomy and medical imaging, in some cases to the exclusion of cadaveric anatomy (McLachlan et al., 2004); however, "traditional" methods of anatomy teaching are still the central teaching method in many institutions (McLachlan and Patten, 2006; Drake et al., 2009).

The two major resources in traditional anatomy teaching are the cadaver and the textbook; however, both have their unique advantages and disadvantages. The cadaver gives the student an opportunity to observe the structures of the body in situ, studying their relations to other structures in three-dimensional space and allowing the student to gain familiarity with the textures, strength, and other physical characteristics of the bodies' numerous different tissues. In addition, students may be exposed to pathological conditions and/or anatomical variations during the dissecting process, which enhances their learning experience. Through the use of prosection, cadaveric material can be expertly dissected to show students exactly what is intended for them to see without risk of it being damaged by inexperienced hands.

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The cadaver, while being the pinnacle of displaying physical and spatial information in anatomy, is limited in its ability to confer theoretical information. Textbooks are used in conjunction with cadaveric material to aid the student in identifying the 3D structures and make links between form (anatomy) and function (physiology). A textbook can be easily used independently of the cadaver for learning and can be taken for private study; however, it can only display visual information on an anatomical structure through diagrams or photographs which are presented in a two-dimensional plane on the textbook's pages.

Additionally, textbooks often cannot realistically take into account the level of detail required by the reader, and a comprehensive textbook may have a great deal of information which is beyond the required level for a student just beginning to learn the subject. Students do not have free access to cadaveric material to study regional anatomy using prosections whenever they wish to do so. Access to such material is strictly controlled (Human Tissues Act, 2004) so that it is made available only during timetabled classes, which further limits student time with such teaching aids (Jones, 1997; Winkleman, 2007; Mukhtar et al., 2009).

One compromise between prosection and textbook would be use of plastic models to study anatomy. This would combine the advantages of presenting a structure in three-dimensional space without the limitations of cadaveric study. However, these models are both expensive for student use, and the decline of their manufacture in recent years serves to exacerbate this (Nicholson et al., 2006).

A novel pedagogy that has emerged in the past 15 years is computer aided learning (CAL). In the field of anatomy, there has been research into the use of three-dimensional computer models, and reviews of the literature (Ruiz et al., 2009; Tam et al., 2009; Tam, 2010) suggest that CAL can indeed compliment anatomical learning, but warn that more research needs to be conducted before it can be widely accepted as a valid standalone teaching method.

Existing medical imaging libraries have been used to create three-dimensional virtual reality anatomy models (Neider et al., 2000; Trelease and Rosset, 2008; Petersson et al., 2009) with some success. Although it can be argued that reconstructing 3D models from CT and MRI scans is perhaps the most logical method, as it familiarizes medical students learning anatomy with interpreting imaging techniques, CT and MRI scans may be difficult to interpret by nonmedical anatomists and those who are inexperienced or new to anatomy teaching.

Second year students undertaking the Human Anatomy Research Skills Module (RSM) at the University of Manchester are expected to learn the musculoskeletal anatomy of either the lower limb or forearm by using traditional teaching methods. To improve anatomical understanding and aid learning of forearm anatomy, it was thought that a rotatable 3D virtual reality model could be produced for these students. The resource would take the form of a "3D diagram" of the forearm which combines the spatial information of a prosection with the clear imagery and relevant basic scientific content distilled from what could be found in a textbook. By combining visual and kinesthetic learning styles, a learning resource for forearm anatomy aimed at a beginner was produced.

Aims

The aim of the research was to determine whether or not a virtual reality forearm would be as effective a learning resource as traditional methods of basic anatomy teaching.

MATERIALS AND METHODS

Software

To construct the 3D diagram, the open-source 3D graphics application Blender, version 2.49b for Windows 32 bit (Blender Foundation, Amsterdam, Netherlands) was used. It could be used across many different platforms, including Microsoft Windows 2000, XP, or Vista, 7 (Microsoft, Redmond, WA) and Mac OS X versions 10.3+ (Apple, Cupertino, CA), and files created on one platform were cross-compatible with the others. Blender had lower system requirements, a relatively small file size and free availability compared to commercial competitors.

The design process for the resource followed the well-established ADDIE model (Peterson, 2003) found in the field of instructional design. The acronym stands for analysis, design, development, implementation, and evaluation and following the model allows a clearly defined set of steps in creating an effective learning resource.

Analysis

The target group of the resource was the Human Anatomy Research Skills Module (RSM) class studying in their second year in the Faculty of Life Sciences, University of Manchester. As a major component of the four-week RSM, the students were taught the anatomy of a human limb, with some studying the forearm and the remainder studying the lower limb. To assess level of anatomical detail required in the resource, RSM teaching staff were questioned about the level of understanding expected of the students.

Design

A freely rotatable model of the human forearm containing bones and muscles of the anterior compartment, along with their attachment points, was constructed and displayed entirely using Blender. The model could be rotated on a simulated three-dimensional axis to view it from all angles with a small block in rotation in the *y* axis to keep attention focused on the anterior of the forearm. Individual muscles could be selected using the left mouse button, and clicking one caused information on the muscle to be displayed. Clicking the selected muscle a second time made all other muscles transparent, therefore isolating the muscle in situ with the bones (Fig. 1).

The model was set within the graphical interface, which displayed which muscular layer was being viewed, and information pertaining to any muscle was selected.

The resource was designed to display only essential information to the user complimentary to the view of the model at any one time. For example on selecting a particular muscle, the name, origin, insertion, and neurovascular supplies of only that muscle were displayed.

In addition, a muscle could be isolated from all others allowing the user to view the individual selected muscle and the bones of the upper limb, allowing full view of the muscle's attachment points and position in space in relation to the bones.

A simple two-button mouse control scheme was used with the left mouse button used to click and select components of the resource, as is standard across many programs and operating systems. The right mouse button would function to rotate the model through a "click and drag" action.

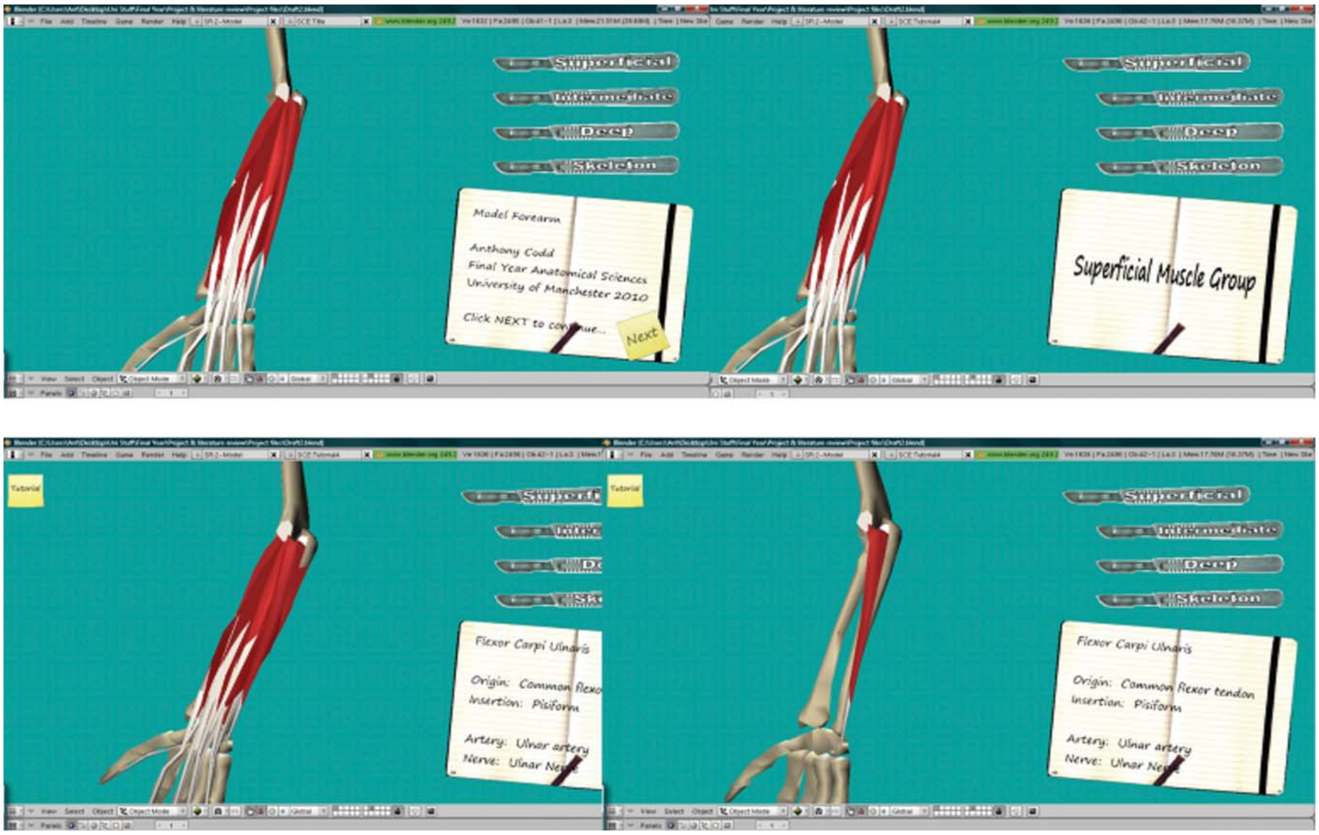

Figure 1.

Screen captures of the resource showing the superficial group of muscles in the anterior compartment of forearm. Different muscle groups can be selected for study with the ability to isolate muscles and learn more about their origins, insertions and actions.

The resource contained a fully 3D model of the human forearm containing the bones of the arm, forearm, wrist, and hand along with the muscles of the anterior compartment of the forearm. Screen captures can be seen in Figure 1.

Development

Feedback was collected at different stages of development from staff and students in the Faculty of Life Sciences at the University of Manchester. This helped to identify improvements to the design, which improved the usability and quality of the final resource. The resource took approximately 60 hours to complete from design to final product.

Implementation

Three testing groups were identified from the cohort of RSM students. Students who had studied forearm anatomy as part of the RSM using the traditional methods were designated the traditional group and were used as a benchmark for measuring the test scores of the resource against. They had received seven hours of structured teaching including five hours of dissection and two hours of study on forearm cross-sectional anatomy in preassigned groups of four students. During these sessions, a tutor, textbooks, prosections, and dissection manuals were available for consultation.

The remaining students had formally studied lower limb anatomy and were split into a further two groups designated “control" and “model.” These students were asked if they had previously studied forearm anatomy (if they had they were excluded from the study), if they regularly engaged in painting, sculpture, carpentry, and/or 3D graphic design and how much experience they had playing 3D video games (none, less than once a month, more than five times a month, or somewhere between once and five times a month). This ensured that there was no significant difference between groups with regard to previous experience with visual–spatial tasks (Nicholson et al., 2006). This also identified if any potential advantages could be gained by students familiar with manipulating 3D environments or objects, such as by playing video games.

All methods used and questionnaires given to participants were passed through the ethics committee of the University of Manchester.

Care was taken to ensure that the subject of the resource was not revealed until necessary so that the groups could not revise or learn forearm anatomy and gain an advantage in the knowledge assessment.

Only the model group was exposed to the resource in a setting as close as possible to the one experienced by the traditional group when learning forearm anatomy. To mirror the methods used in the RSM, the model group used the resource in groups of four and had an anatomist and text-books at hand to consult.

Distribution. The model group was exposed to the resource in groups of four, as per the group sizes for the RSM module. The model was digitally projected inside a classroom within the dissecting room. Groups of participants took between 30 minutes and one hour (average 50 minutes) with the resource before taking the knowledge assessment. All assessments were conducted in a separate part of the dissecting room away from the classroom and main laboratory area.

Knowledge assessment. To assess the level of existing knowledge in the control and traditional groups, and knowledge of the model group following exposure to the resource, all students participating were subjected to a ten question forearm anatomy practical assessment. Thirteen structures were labeled A–M using pins on two prosected forearms, one dissected to the superficial layer and a second dissected to show the deep layer of the anterior compartment. Examples of structures labeled are Flexor carpi ulnaris (labeled A), Pronator quadratus (labeled H), and the Median nerve (labeled K). The knowledge assessment contained questions regarding muscle names, locations, actions, and neurovascular supply. Some questions were straightforward (Name structure A) while others were more challenging [Which muscular structure (A–H) is not innervated by nerve K?)].

Students were scored in marks out of 10. Students in all groups were tested individually and were permitted to handle the specimens. The control and traditional group needed no preparation for the assessment and were not told what anatomical region the assessment would involve until the beginning of the assessment. This ensured that no preparation could be undertaken on the part of the students that may have compromised the validity of the results. The control group had no previous knowledge of forearm anatomy, whereas the traditional group had the knowledge obtained from learning forearm anatomy from the traditional style of teaching during the RSM.

The model group were assessed within 30 minutes of using the resource and were assessed individually using the same question set and forearm prosections as the other two groups. The same forearm specimens were used for all assessments.

Resource feedback. After using the resource, the model group was asked to fill out a resource feedback questionnaire regarding the usability of the resource, and to gather information on student's perceptions of virtual reality when compared to learning anatomy with traditional methods. Nine questions were asked which could be grouped under two headings: usability of resource and relevance of resource compared to traditional methods of teaching anatomy.

Data processing. Data obtained from the knowledge assessment was analyzed using SPSS version 18.0 (SPPS, Chicago, IL). A Kolmogorov–Smirnoff test was used to determine the distribution of the data, and then an analysis of variance (ANOVA) was done to compare the means of all three groups. A Tukey's range test determined if there was any significance between any of the three groups in terms of mean test scores.

Baseline data for all groups were compared using χ^2 tests for differences.

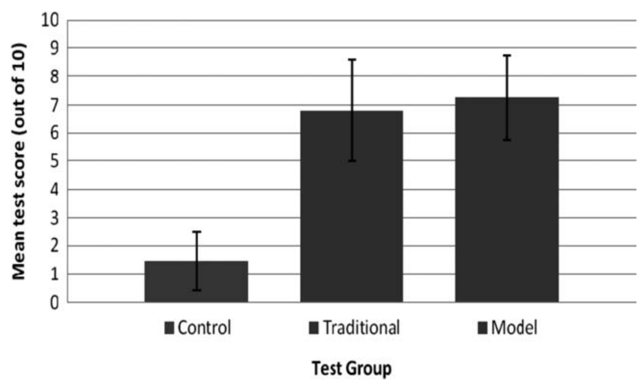

Figure 2.

A bar chart representing a comparison of mean knowledge test scores of each test groups including standard deviation.

RESULTS

Of the 46 identified potential participants, 39 took part in the study—a participation rate of 85%. The sizes of the groups were: traditional group $n = 14$, control group $n = 13$, and model group $n = 12$.

Evaluation

Baseline data. There was no significant difference between the groups with regard to baseline factors such as previous experience with visio-spatial tasks, and it was confirmed by the pretest questionnaire that only the traditional group had been taught forearm anatomy previous to commencement of this research.

Knowledge test. Using the resource significantly improved knowledge of forearm anatomy compared to the control group ($P < 0.001$). As expected, the mean test scores of the traditional methods group were also significantly higher than the control group ($P < 0.001$). There was no significant difference ($P < 0.5$) between the mean test scores of the traditional methods group and the model group (Fig. 2). The F value for the ANOVA was 60.25, confirming that the test was highly significant.

There was no correlation identified between visio-spatial experience and test scores. The model group participants were split into subgroups depending on their answers to the question on the preassessment questionnaire regarding previous experience with 3D video games. The mean test scores for each subgroup were compared to assess any differences. The means for the subgroups were: 7.6 for the group that had never played 3D video games ($n = 3$), 7.3 for the group that played sometimes ($n = 6$), 5.0 for the group that played a moderate amount ($n = 1$), and 7.5 for the group that played lots ($n = 2$).

Resource feedback. A resource feedback form was given to all 12 participants who had used the resource. Ten questionnaires were completed and returned; the results are depicted in Figure 3. When asked about what they enjoyed the most from the resource, key positives identified were the ability to rotate the model in 3D, the presentation of information in a clear and concise way, the isolation feature, and

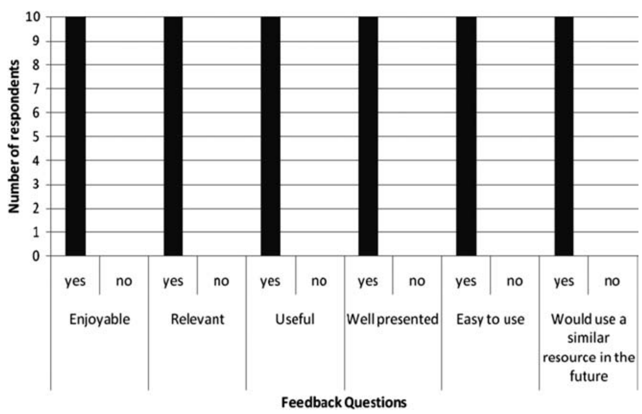

Figure 3.

A bar chart representing student responses to questions posed on the resource feedback questionnaire.

the overall interactivity. The single negative comment was regarding the initial presentation of the model, commenting that it was difficult to distinguish between different muscles when viewing the model with all structures visible.

When comparing the resource to learning with traditional methods the consensus was that the resource was much better than using a textbook alone but not as good as using dissection and prosection. It was identified by the respondents as being complimentary to traditional methods, with one stating that it would provide an excellent precursor to formal teaching sessions.

DISCUSSION

The data collected for this research suggest that the electronic resource was well received by the students that used it, and that it can significantly improve the anatomical knowledge of users, similar to those learning using traditional methods.

Resource Effectiveness

The mean knowledge test scores of the model group were significantly higher than those of the control group which gives strong evidence that the resource could be a valid method for teaching forearm anterior compartment musculoskeletal anatomy.

In this study, the mean knowledge test scores for the model group were not significantly different to those of the traditional group. This finding suggests that the resource is an effective tool in helping students learn forearm anatomy to a similar standard as traditional methods. This is consistent with findings from other studies where use of an e-resource significantly improved anatomical knowledge test scores (Hallgren et al., 2002; Elizondo-Omana et al., 2004; Kurihara et al., 2004; Qayumi et al., 2004; Nicholson et al., 2006). The results come as a contrast to earlier research which was inconclusive (Garg et al., 1999, 2001, 2002), or showed no significant improvement in anatomy test scores after using CAL resources (Devitt and Palmer, 1999). These studies are, however, different from this research in the way that they either assess how CAL can be used to supplement existing anatomical teaching methods (Hallgren et al., 2002; Elizondo-Omana et al., 2004; Qayumi et al., 2004) or how 3D models can be used to improve learning resources (Garg et al., 1999, 2001, 2002; Nicholson et al., 2006).

Only one study was found that directly compared virtual reality anatomy to traditional methods (Hisley et al., 2008). The study, in concurrence with the results presented here, found that using virtual reality was as effective at teaching anatomy as traditional methods such as dissection with no significant difference in assessment performance between test groups using virtual dissection and traditional dissection.

As there was no correlation found between 3D video game experience and test scores, those with little or no previous experience in this form of virtual environment can still obtain high knowledge assessment scores. This supports the design of the resource suggesting that it is intuitive and easy to use. Whereas Nicholson et al. (2006) collected information from participants of their study regarding previous 3D video game use, this information was used only to compare groups and not to analyze correlation between 3D video game use and test scores.

Feedback from the ten responding resource users was unanimously positive with regard to presentation, content, and functionality, which indicates that anatomy students have a positive attitude toward the resource. These results agree with previous findings that computer-aided anatomy learning is well received by students (Lynch et al., 2001; St Aubin, 2001; McNulty et al., 2004, 2009).

Feedback from participants suggested that this method of learning compared favorably to textbooks, but not to dissection, in agreement with Petersson et al. (2009). While this is positive, it must also be considered that there may be an element of novelty to the resource which could increase user interest over textbooks which the participants would be used to as a "standard" source of learning anatomy.

The main aims of the resource were met and the resource was found to be just as effective as traditional methods for teaching the basic musculoskeletal anatomy of the anterior compartment of the forearm. Although the resource was shown to be just as effective as traditional methods for teaching the spatial and theoretical aspects forearm anatomy, it is not anticipated that it could form a replacement for dissection. A model cannot convey tactile information to the student and this is considered an important advantage of using cadaveric material (Crisp, 1989; Hill and Anderson, 1991; Pabst, 1993; Marks, 1996; Jones, 1997; Moore, 1998), and this can be seen as a limitation of virtual reality anatomy. Furthermore variations, whether common or rare, cannot effectively be displayed in such simulations. The "joy" of discovering anomalies in anatomy is lost when using computer simulations. This is a unique and important learning point when using cadavers. As previously mentioned, the cadaver displays spatial information in a way other methods cannot emulate. The e-resource produced did not show any neurovascular structures in relation to the muscles and bones. Given enough time, this could have been achieved although the relations and course of arteries and nerves can best be understood using dissection/prosections.

The results of the knowledge assessments and participant feedback show that the most valuable situation for the resource is as a precursor and complimentary tool to traditional methods as opposed to a replacement. This finding is in accordance with the general opinion regarding CAL in anatomy which is that anatomists are unlikely to be forced to choose between either cadaver and computer, and therefore the two methods should be used to their own unique advantages (Jones, 1997). Adopting an integrated approach should ensure that the anatomy being learned in an effective manner (Chao et al, 2007).

Experimental Design

The resource produced was a compromise between performance and detail and as such the model was more stylized in its presentation. Perhaps this style of presentation was more appropriate to the target group who were only learning the basics of forearm anatomy, where excessive detail would have held very little benefit. The stylization also allowed the model to better fulfill its intended form as 3D diagram, as diagrams often omit unnecessary detail for clarity.

Other suggestions that could not be included due to time constraints included highlighting of muscle groups or assigning different colors to individual muscles to improve clarity of the individual structures. The addition of colored patches or outlines on the skeletal layer was also suggested to show individual muscle origins and attachments.

Knowledge assessments were undertaken in a separate part of the gross anatomy laboratory, which allowed individuals to be tested in a quieter environment and prevented other participants from eavesdropping and potentially invalidating data.

While as tightly controlled as possible, due to the coordination required with the RSM some differences did occur between the traditional and model groups. The only planned differences between the model group and the traditional group were the use of either the resource model or cadaveric dissection and the time each group was exposed to these. The increased learning time in the traditional group may have given them an advantage when it came to the knowledge assessment; however, in the RSM they are required to learn the muscular anatomy of the posterior compartment of the forearm in addition to the anterior compartment. This was a greater volume of knowledge than required from the model group. Another source of variation between groups came from the lapse in time between learning and assessment. The traditional group was assessed within five days of concluding their formal anatomical study, whereas the model group was assessed within 30 minutes of using the resource. While this may have given the model group an advantage this cannot be certain without a follow-up assessment for the model group at five days postresource use, which was not possible due to time constraints imposed by the RSM.

It is possible that as participation was voluntary, those that actually took part out of the identified groups were inherently more motivated to learn forearm anatomy. This may have meant that the less motivated and potentially lower scoring individuals were not tested. However, as this was the case for all groups, it is not thought that much error could arise from this.

CONCLUSIONS

The resource met the initial aims by providing learning outcomes comparable to those expected from traditional anatomical teaching methods. The success of the resource has led to its incorporation into the RSM for future academic years, where it will be used complimentary to traditional methods. Although the results are positive, it is not our recommendation that such a computer package could replace traditional methods of teaching forearm anatomy. It is a very useful adjunct to reinforce the traditionally taught anatomy. The results of this study are promising, so further studies with larger sample sizes would be an appropriate extension.

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