Efficacy of Video-Based Forearm Anatomy Model Instruction for a Virtual Education Environment

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ABSTRACT

INTRODUCTION: As virtual education becomes more widespread, particularly considering the recent COVID-19 pandemic, studies that assess the impact of online teaching strategies are vital. Current anatomy curriculum at Paul L. Foster School of Medicine consists of self-taught PowerPoint material, clinical vignette-centered team-based learning (dry lab), and prosection-based instruction (wet lab). This study examined the impact of video-based muscle model (VBMM) instruction using a student-designed forearm muscle model on anatomy quiz scores and student perceptions of its effectiveness with regards to learning outcomes.

METHODS: Students divided into Group 1 (54 students) and Group 2 (53 students) were assessed prior to and following a 3.5-minute video on anterior forearm compartment musculature using the muscle model. Group 1 began by completing a pretest, then received VBMM instruction, and then completed a posttest prior to participating in the standard dry lab and 1 hour wet lab. Group 2 completed the wet lab, then received the pretest, VBMM instruction, and posttest prior to participating in the dry lab. Both groups took an identical five-question quiz covering locations and functions of various anterior forearm muscles each time.

RESULTS: Mean scores were higher than no formal intervention with exposure to VBMM instruction alone (0.73 points, $P = .01$), wet lab alone (0.88 points, $P = .002$), and wet lab plus VBMM instruction (1.35 points, $P = <.001$). No significant difference in scores was found between instruction with VBMM versus wet lab alone ($P = 1.00$), or between either instruction method alone compared to a combination of the two methods ($P = .34, .09$). Student survey opinions on the VBMM instruction method were positive.

CONCLUSION: VBMM instruction is comparable to prosection-based lab with regards to score outcomes and was well received by students as both an independent learning tool and as a supplement to cadaveric lab. When compared to either instruction method alone, the supplementation of VBMM with cadaveric prosection instruction was best. VBMM instruction may be valuable for institutions without access to cadaveric specimens, or those looking to supplement their current anatomy curriculum.

KEYWORDS: anatomy, education, medical curriculum, video, forearm, virtual, physical model, prosection

TYPE: Original Research

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Introduction

Anatomy is an intricate, but foundational, component of first-year medical school education. As the virtual learning environment becomes more widely utilized, particularly in light of the recent COVID-19 pandemic, the exploration of online teaching strategies is vital. Current first-year anatomy curricula at the Paul L. Foster School of Medicine (Texas Tech University Health Sciences Center, El Paso, TX) follows a clinical scheme-based, organ systems approach and consists of self-taught PowerPoint (lecture) material, team-based learning using clinical vignettes (dry lab), and prosection-based (wet lab) instruction. Anatomy teaching methods continue to be evaluated and researched[1] with no evidence-based gold standard.

Anatomy instruction is generally classified into two main modalities: lecture and laboratory teaching. Notwithstanding the separate debate of in-person versus virtual lecture instruction, the "hands-on" or visual laboratory (lab) instruction modality is popular and perhaps necessary to fulfill anatomy learning objectives. Given the importance of the lab modality of anatomy instruction, the focus of the present study is lab instruction pedagogies. Anatomy lab instruction can be further categorized into (a) wet lab dissection-based teaching, (b) wet lab prosection-based teaching, (c) dry lab model-based teaching, and (d) virtual digital-media teaching, as well as hybrid models among the four.

Dissection has been, and continues to be, a heavily relied upon and highly regarded medium of anatomy instruction.[2–4] However, the limitations of dissection-based anatomy instruction, including demands on curricular time, cost, labor, resources, and trained faculty, are driving forces behind the transition to alternate pedagogies.[2,5,6] In addition, this type of wet lab instruction has been criticized by students for prioritizing dissecting skills at the expense of clinical application of

anatomy.[4] Importantly, other teaching modalities have been found to be comparable to dissection in terms of learning outcomes, including the use of models.[1]

Prosection-based instruction has resulted in anatomy scores that are equivalent to those of medical students who participated in dissection.[1,7–9] In their review of anatomy teaching practices, Estai and Bunt cited various studies which recognized advantages of prosection over dissection, including time efficiency, course flexibility, and the need for fewer cadavers.[2] Students could not only see structures more clearly, but they also had more opportunities to observe multiple specimens and their anatomical variations. Nevertheless, the authors still noted the demands on time and the need for trained individuals to prepare the prosected specimens.

Alternatives to cadaver-based education include the use of virtual dissection, media, and models. A study comparing forearm musculoskeletal anatomy education using virtual reality (VR) computer models to a more traditional dissection and textbook approach found no difference in quiz scores between the two groups.[10] Video instruction has been used for years as a supplement to traditional anatomy lectures to teach complex topics in a way that is understandable and visually engaging.[11] Computer-aided instruction has proven to have positive outcomes on learning outcomes when used in the context of a traditional gross anatomy curriculum, as evidenced by an increase in exam scores among students who used the learning resource frequently compared to those who did not.[12] The computer-aided instruction was used as a supplement to textbook reading, lecture, and cadaveric dissection, but was also heavily relied on as a guide for student dissections. Specifically, instructional gross anatomy videos using cadaveric structures resulted in higher anatomy exam scores among first-year medical students, and were found to be most useful as a preparatory resource in supplement to the large group teaching style of a gross anatomy lab.[13]

The use of models is established and provides some solutions to the aforementioned problems with cadaveric instruction, particularly their longevity.[14,15] Physical models have been found by some studies to be more effective than computer-based modalities, virtual dissection and cadaveric dissection, a difference that has been attributed to the simplicity, ease of use and opportunity for physical manipulation associated with the physical model.[16–18] Yet, a meta-analytic comparison of dissection to prosection, digital media, model, and hybrid teaching formats found no significant differences among learning outcomes.[1] Recently, a study comparing anatomy education of the upper limb using plastic models compared to prosections found no statistically significant difference in scores out of anatomy examinations.[19] The study concluded that physical models are an effective supplement to cadaveric teaching and are appreciated by medical students. 3D printed models, in particular, have also resulted in anatomy exam scores that are equivalent to conventional learning via cadavers and 2D images, though the group taught via 3D printed models had a statistically significant decrease in question answering time.[20]

In recent years, the use of virtual and augmented reality (AR) for the purposes of teaching anatomy has become more prevalent. Technology such as this allows students to interact with either a virtual environment, or their surrounding environment with a virtual overlay. When compared to textbook or 2D image-based teaching styles, these technologies allow students to experience anatomy in three dimensions. One study on AR use for anatomy education found that this teaching method improved test scores and was an enjoyable learning method for students; AR was recommended to be used as a supplement to traditional teaching methods.[21] A systematic review and meta-analysis found no statistically significant difference in scores between VR or AR teaching versus traditional teaching methods such as textbooks, lecture presentations, or phone applications.[22] The authors concluded that VR and AR teaching methods may improve spatial understanding of anatomy and is an effective alternative to other traditional pedagogies. Another meta-analysis found a statistically significant increase in exam scores when comparing the use of VR and traditional teaching methods, and students found VR to be more interesting of a learning method.[23]

Student attitudes about dissection and prosection are mixed.[24–26] While Dinsmore et al found that students prefer prosection over dissection[26], other studies have found that dissection is favored.[24,25] A study by Dissabandara et al found that although students had positive perceptions of dissection, only 36% of students considered dissection as a preferred method of learning anatomy.[27] However, student perceptions of anatomy instruction efficacy seem to favor both dissection and prosection over model-based teaching.[24] Students have found that the use of 3D printed models as a supplement to plastinated or wet cadaveric prosection was beneficial to their learning of upper limb anatomy but generally do not want this to replace cadaveric instruction.[28] The implementation of multimedia has been shown to improve student interest and learning generally.[29] Students have noted that the use of video-based anatomy instruction contributes to a deepened understanding of the material and serves as a substitute for tutor assistance.[30] Perceptions of VBMM instruction in supplement to prosections have not been investigated.

The purpose of the present study was to examine the impacts of video-based muscle model (VBMM) instruction in a dry lab on quiz scores and perceptions of first-year medical students, with (Group 2) and without (Group 1) prior exposure to the prosection-based wet lab. In a scholastic world that is rapidly transitioning to a distanced and virtual format, particularly in light of the recent COVID-19 pandemic, studies exploring new digital teaching strategies are essential. Additionally, institutions with limited access to cadaveric donors or trained anatomy faculty need alternative strategies to teach anatomy. The forearm musculature serves as an intermediate challenge

for students learning anatomy due to the complexity of the muscle compartments, layers, and functions and was therefore an appropriate anatomical region to use in this study. Both exam scores and student perceptions about the educational quality of the VBMM instruction and its utility as a supplement to prosections were evaluated as outcomes. Our hypothesis regarding quiz score outcomes, which was the null hypothesis, was that there would be no significant differences between quiz scores when the wet lab and VBMM modalities were combined when compared to VBMM alone. Our hypothesis regarding student perceptions was that students would have positive opinions about VBMM instruction alone, and in supplement to wet lab.

Methods

This study was approved under the exempt category (#E20091) by the Institutional Review Board (IRB) at Texas Tech University Health Science Center El Paso on June 3, 2021. As this study was granted exemption from IRB review, consent documentation was not necessary. Additionally, the use of an anatomy lab quiz is a standard requirement of the school's curriculum and was used for the purposes of this study to assess anatomical knowledge of the anterior forearm musculature before and after VBMM instruction. The survey administered was voluntary and anonymous and was used to assess the participants' opinions on VBMM instruction. The participants were informed about the purposes of the study and the nature of their involvement as participants.

We integrated the experiment into the forearm anatomy lab of the fall 2019 musculoskeletal unit for the first-year medical students at the Paul L. Foster School of Medicine (Texas Tech University, El Paso, TX). One hundred and seven (n = 107) first-year medical students who attended lab that day comprised Group 1 (n = 54), who began with the TBL (team-based learning) dry lab, and Group 2 (n = 53), who began in the prosection-based wet lab. Although groups were not randomized for the sole purpose of the present study, students were randomly divided into two groups at the beginning of the school year, which conveniently established the group compositions. The students had an online self-study PowerPoint document covering the forearm anatomy available to them prior to the lab, as is typical of all lab sessions at the school. The presentation contained anatomical diagrams, tables, and text covering the same objectives as the wet lab. However, we could not control for whether or not students accessed these materials. As this was self-study material that was not recorded as mandatory, we did not consider this to be formal instruction. This has been noted as a limitation in the limitations section of the manuscript.

Group 1 began in the TBL room and prior to any formal instruction, received a 5-minute, five-question quiz covering locations and functions of anterior forearm musculature. Group 1 then watched a 3.5-minute instructional video using the muscle model on one of the 10 television screens around the dry lab room, and subsequently retook the same five-question quiz. Group 2 began in the wet lab. After completing the wet lab portion of instruction, they rotated to the TBL room, where Group 2 took the same quiz, watched the same VBMM instruction, and then took the same quiz again. Therefore, we collected a total of four data subsets: Group 1 pretest scores represent no formal instruction; Group 1 posttest scores represent VBMM instruction only; Group 2 pretest scores represent the wet lab prosection instruction only; and Group 2 posttest scores represent both VBMM and wet lab prosection instruction methods. Groups 1 and 2 did not interact with one another during their transition to the opposite lab room. Although we collected pre- and posttest scores similarly to a within-subjects experimental design, we did not pair data and therefore each of the four data subsets was treated as an independent sample. Accordingly, we compared data subsets via Kruskal–Wallis test.

The 3.5-minute instructional video reviewed the locations (origin, insertion, and spatial relationship to other muscles) and functions of all anterior forearm musculature and the brachioradialis muscle using a student-designed muscle model (Figure 1). A human actor demonstrated the actions of the muscles in the video. The prosection-based wet lab instruction lasted 1 hour and consisted of 10 stations, covering the forearm and wrist. Stations were either independent, faculty guided, or guided by a second-year medical student teaching assistant. The objectives of the wet lab session/self-study presentation included:

- Identify the prominent features of the humerus, ulna, radius, carpals, metacarpals, and phalanges of the associated extensor and flexor compartments as given in the lab manual.
- Identify the extensor and flexor compartments of the forearm and hand, the nerve and vessels supplying their contents, and the functional significance of the included muscles.
- Correlate any fractures or deep cuts of the forearm or hand with functional disruptions of associated muscular or neurovascular structures.
- Describe the movements of elbow, wrist, and finger joints.
- Identify the position of tendons and associated bursae beneath the extensor retinaculum and palmar carpal ligament.

The five-question quiz was multiple-choice, administered anonymously in person using pen and paper, and covered the locations and functions of anterior forearm musculature and the brachioradialis muscle. We modeled the quiz questions after retired anatomy exam questions were available on the Texas Tech University Health Science Center, Paul L. Foster
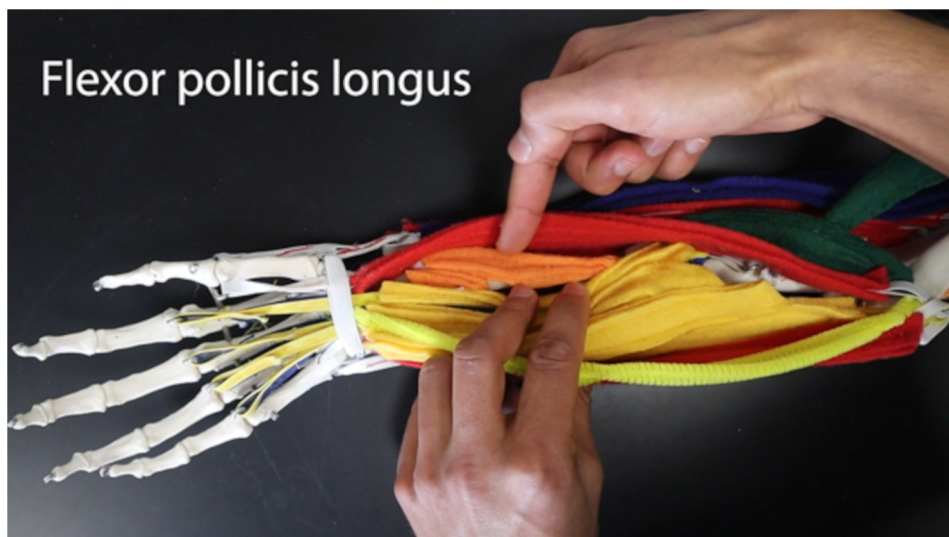
Figure 1. The student-designed forearm muscle model is being used in the instructional video to demonstrate the location and function of the flexor pollicis longus. Fabrics in different colors were used to represent the various anterior forearm muscles and were connected to their approximate corresponding origins and insertions on a synthetic skeletal forearm.

Table 1. Five-question multiple-choice anatomy quiz questions, answers, and distractors.

Question	Answer	Distractors
What deep muscle of the forearm flexor compartment has both its origin and insertion located most distally on the forearm?	Pronator quadratus	1. Pronator teres 2. Palmaris longus 3. Flexor pollicis longus
Which superficial forearm flexor is located most medially on the forearm in anatomical position?	Flexor carpi ulnaris	1. Flexor carpi radialis 2. Brachioradialis 3. Pronator quadratus
A boy falls and lacerates the radial side of his forearm, losing some ability to flex his elbow. Which of the following muscles was most likely injured?	Brachioradialis	1. Flexor carpi radialis 2. Flexor pollicus longus 3. Palmaris longus
An overweight young adult male suffers a spontaneous muscle rupture causing loss of function of thumb flexion. Which of the following muscles was most likely affected?	Flexor pollicus longus	1. Extensor digiti minimi 2. Brachioradialis 3. Flexor digitorum superficialis
Which of the following muscles is NOT a muscle of the superficial forearm flexor compartment?	Flexor digitorum profundus	1. Flexor carpi radialis 2. Pronator teres 3. Palmaris longus

School of Medicine Gross Anatomy website.[31] We graded the quiz on a 5-point scale. The five quiz questions, answers, and distractors are listed in Table 1.

While taking the quiz, students were aware that their quiz grade was not recorded to impact their overall course standing. We administered an anonymous, voluntary Likert scale survey to all students following the entire lab instruction procedure on the same day. The survey items and responses are shown in Figure 2. We modeled the survey items after valid and reliable survey questionnaire items used in two medical education studies on student perceptions of anatomical science teaching strategies.[32,33] We administered the survey digitally via commercially available software (SurveyHero, version Basic, enuvo GmbH).

We assessed the normality of test score distributions using the Shapiro–Wilk test. We used the Kruskal–Wallis test to compare among mean ranks of Group 1 (pre- and posttest) and Group 2 (pre- and posttest). Follow-up analyses included all pairwise comparisons Mann–Whitney U tests with a Bonferroni correction. We set the *a priori* alpha level at $P \leq .05$ and performed all statistical analyses using commercially available software (IBM SPSS, version 26). We reported individual survey item responses according to the number of responses per Likert scale without separating responses by Group.

Results

Quiz score distributions are shown in Figure 3. None of the quiz score subsets were normally distributed, including Group 1 pretest scores ($W = .93$, $P = .004$), Group 1 posttest scores ($W = .91$, $P = .001$), Group 2 pretest scores ($W = .89$, $P = <.001$), or Group 2 posttest scores ($W = .84$, $P = <.001$).
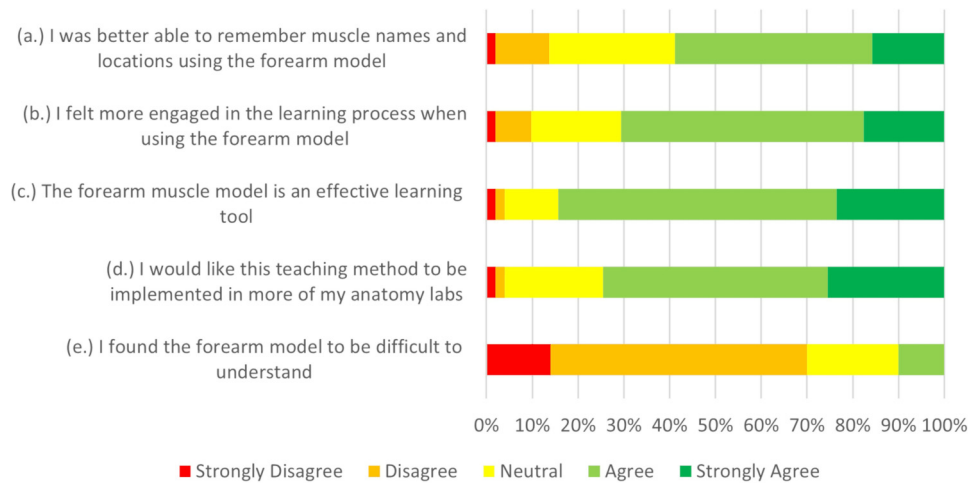
Figure 2. Likert scale results for the following student perceptions of the VBMM instruction where red represents Strongly Disagree, orange represents Disagree, yellow represents Neutral, light green represents Agree, and green represents Strongly Agree: (a) respondents who felt they were better able to remember forearm muscle names and locations (n = 51); (b) respondents who felt more engaged in the learning process (n = 51); (c) respondents who considered the model an effective learning tool (n = 51); (d) respondents who supported the implementation of this teaching method in future anatomy labs (n = 51); and (e) respondents who found that the forearm model was difficult to understand (n = 50).

The omnibus Kruskal–Wallis indicated differences among mean ranks of test scores (H = 30.93, P = < .001). Follow-up Mann–Whitney U pairwise comparisons (with Bonferroni corrections) indicated that Group 1 demonstrated an increase (P = .01) in mean quiz score from pre- to posttest of 2.57 to 3.30. However, there was no statistically significant difference (P = .34) between the mean pre- and posttest scores of Group 2 (Table 2). Group 1 mean pretest scores were lower than (P = .002) Group 2 mean pretest scores and Group 2 mean posttest scores (P = < .001, Table 2). There was no statistically significant difference between Group 1 mean posttest scores and Group 2 mean pretest scores (P = 1.00) or Group 1 mean posttest scores and Group 2 mean posttest scores (P = .09, Table 2).

Fifty-one (n = 51) students completed the first four survey items, while n = 50 completed the fifth item, which represents a 47% to 48% response rate. The results of the Likert scale survey are shown in Figure 2. Regarding the VBMM instruction method, 59% (n = 30) of respondents felt they were better able to remember forearm muscle names and locations when combining Agree and Strongly Agree Likert scales. Likewise, 71% (n = 36) felt more engaged in the learning process, 84% (n = 43) considered the model an effective learning tool, and 75% (n = 38) supported the implementation of this teaching method in future anatomy labs. Only 10% (n = 5) of respondents found that the forearm model was difficult to understand.

Discussion

The statistically significant higher scores for Group 1 posttest and Group 2 pretest, when compared to Group 1 pretest, indicate that both VBMM and prosection-based lab instruction methods individually improve learning outcomes. The effectiveness of both physical anatomy models and prosection-based labs is supported in the literature and not unexpected.[1,2,7,8,19,34] Physical anatomy models in particular have been found to improve overall knowledge outcomes and spatial knowledge outcomes.[19,34]

The comparisons of Group 2 pre- to posttest, Group 1 posttest to Group 2 pretest, and Group 1 posttest to Group 2 posttest demonstrated no statistically significant differences in mean scores (Table 2). That is to say: there was no difference in scores between prosection-based lab alone and prosection-based lab plus VBMM instruction; there was no difference in scores between instruction VBMM and wet lab instruction alone; and there was no difference in scores between VBMM instruction alone and prosection-based lab plus VBMM instruction. Therefore, VBMM instruction appears to be comparable to prosection-based instruction at building knowledge of anatomical structure and function. This finding is consistent with a meta-analysis conducted by Wilson et al[1]. In fact, the meta-analytic comparisons of dissection to prosection, digital media, model, and hybrid teaching formats found no significant differences among learning outcomes for any of the teaching modalities.

According to the results of Group 1 pretest versus Group 2 posttest, the combination of prosection-based instruction with VBMM instruction was the most effective in the present study, as it demonstrated the greatest difference in mean scores. Scores were 53% greater in Group 2 posttest than Group 1 pretest by an average of 1.35 points. Evidence of the efficacy of anatomy curricula that integrate multiple pedagogies is not unique. Teaching with combinations of multiple instruction methods is considered to be optimal.[2]
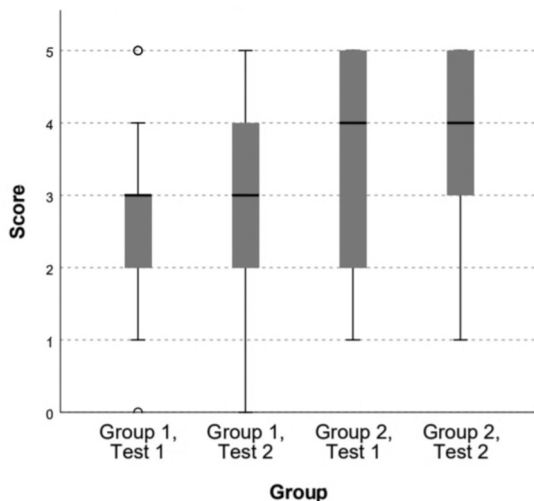
Figure 3. Box and Whisker plots displaying quiz score distributions for Group 1 pretest and posttest and Group 2 pre-test and posttest. Outliers are represented by the open circles but were not removed for the purposes of data analysis.

Based on this study's survey findings, VBMM instruction was considered by the first-year medical students to be effective, engaging, and easy to understand. The results are consistent with a study by Davis et al which found that 94% of first-year and 84% of second-year medical students believe anatomical models are useful educational tools.[25] Both cadaveric instruction and instruction using anatomical models are independently supported by students.[24,34] The present study suggests that students support the implementation of VBMM instruction with their traditional anatomy lab experience consisting of self-taught PowerPoints, prosections, and case-based TBL.

Table 2. Pairwise comparisons of all group quiz score subsets via Kruskal–Wallis test.

Comparison	H Statistic	Adjusted *P*-value	Mean Difference (points)
(a.) Group 1 Pretest to Group 1 Posttest	−35.57	.01	0.73
(b.) Group 2 Pretest to Group 2 Posttest	−22.37	.34	0.47
(c.) Group 1 Pretest to Group 2 Pre-test	−41.53	.002	0.88
(d.) Group 1 Pretest to Group 2 Posttest	−63.90	<.001	1.35
(e.) Group 1 Posttest to Group 2 Pretest	−5.96	1.00	.15
(f.) Group 1 Pos-test to Group 2 Posttest	−28.33	.09	.62

Group 1 pretest scores represent no formal instruction; Group 1 posttest scores represent VBMM instruction only; Group 2 pretest scores represent wet lab prosection instruction only; and Group 2 posttest scores represent both VBMM and wet lab prosection instruction methods. Abbreviation: VBMM: video-based muscle model.

Other benefits of anatomical models include their ability to assist with memory, problem-solving, and student engagement, in addition to their low cost and ease of availability.[34,35] However, Chan and Cheng recognize that the low fidelity of anatomical models to real human body structures is a limitation of their use, and therefore recommend the accompaniment of additional teaching strategies to bridge knowledge gaps.[35]

Not surprisingly, all quiz score subsets were found to be non-normally distributed. These findings are consistent with many previous studies indicating that exam score data is often non-normally distributed.[36] In fact, since the narrow range of grades in the present study occupied only six possible outcomes (ie 0-5), it is safe to assume that such scores could be considered nearly incapable of normal distribution properties. Therefore, the results of the present study in conjunction with commonly accepted practices involving statistical comparisons of quiz scores support the use of nonparametric statistical models to analyze mean comparisons.

Limitations of the Study

This study had some limitations. First, all volunteers (n = 107) comprised a convenience sample, which may not reflect all first-year medical students across all medical school programs. However, these preliminary data suggest that larger, cross-institutional studies are warranted to examine course and time efficiency for first-year anatomy instruction. Second, we did not control whether students previewed the self-taught lecture material prior to attending the lab. While students are typically expected to study the lecture material in advance, there was no record from the instructor as a mandatory assignment. Given the integrated approach of this study, the prosection-based lab was longer (1.5 hours) and covered more material over the forearm and wrist when compared to the VBMM instruction, which was 3.5 min and covered only the anterior forearm musculature. Future studies could be conducted outside of a set curriculum, utilizing a prosection-based instruction session that is more comparable in time and content to the VBMM instruction. Lastly, we collected pre and posttest quiz scores anonymously; therefore, those data were not paired. For this reason, we treated pre- versus posttest quiz scores as between-group comparisons with the Kruskal–Wallis test and follow-up Mann–Whitney U tests. Future studies are needed to anonymously pair the pre- and posttest quiz scores to allow the correlations to adjust the error ratios with a dependent-samples analysis.

Conclusion

In summary, VBMM instruction using a forearm muscle model improved anatomy quiz scores and has a positive effect on anatomy learning outcomes. The teaching strategy appeared to be comparable to prosection-based lab with regards to score outcomes and was well received by students as both an independent learning tool and as a supplement to cadaveric lab.

When compared to VBMM instruction or prosection-based instruction alone, the supplementation of VBMM instruction with cadaveric prosection instruction was best. Institutions transitioning to a virtual learning format, those with limited in-person contact hours, or those struggling with access to cadaveric donors or trained anatomy faculty, may benefit from the incorporation of VBMM instruction into their anatomy curriculum.

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Author's Note

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