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ORIGINAL ARTICLE

Analysis of immediate student outcomes following a change in gross anatomy laboratory teaching methodology*

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Objective: To compare student performance following a change in laboratory teaching methodology from cadavers to models to virtual dissection table in a musculoskeletal gross anatomy course in a doctor of chiropractic program.

Methods: Three marking periods of laboratory and lecture examination scores from 3 consecutive academic calendar years were evaluated and compared using simple analysis as well as analysis of variance and post hoc t tests. The 1st cohort of students ($n = 352$) utilized cadavers. The 2nd cohort of students ($n = 350$) had anatomical models as their primary gross laboratory modality. The 3rd cohort of students ($n = 393$) utilized virtual dissection tables.

Results: The midterm and final laboratory examination scores were evaluated and showed successive increase in aggregate averages between cohort 1 (mean = 76.1%), cohort 2 (mean = 81.4%), and cohort 3 (mean = 85.1%). Lecture examination scores remained consistent between the cohorts at 61.2%, 62.4%, and 61.1%, respectively. Significant improvements were seen in lab exam scores between cohorts (F [2, 2113] = 58.6, $p < .001$), and no significant differences were seen in lecture exam scores.

Conclusion: Students utilizing virtual dissection tables scored higher on laboratory examinations than students having models or cadavers. However, they displayed a similar testing competency in lecture examinations, suggesting a possible change in laboratory examination difficulty between the cohorts but a similar knowledge base. Further studies are warranted to evaluate the long-term retention of student knowledge.

Key Indexing Terms: Anatomic Models; Anatomy; Cadaver; Chiropractic; Education

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INTRODUCTION

As the faculty of health care institutions attempt to adapt curricula to the increasing demands of rapidly expanding student course loads, less class time is devoted to the teaching of foundational anatomy. Many factors have contributed to institutions seeking to ensure competency in anatomy with less curricular time devoted to the subject. The gold standard for anatomy education has long been considered by students, clinicians, and anatomists alike to be the dissection of the human cadaver.[1]

Proponents for retention of the experience of student dissection in anatomy cite advantages such as spatial orientation and visualization of relationships between structures. A cadaver gives regional anatomy a context in the entire organism and imparts an appreciation of anatomical variability between individual specimens.[2] Exploring how an individual's anatomy adapted to stress and disease gives an appreciation of the resilience of the human species. It is thought by many that a student's ability to diagnose and manage patient care will be significantly inhibited by the removal of cadavers from the educational experience of medical students.[3] This holds especially true in the education of future surgeons where competency in human anatomy is most vital. Removal of cadavers from the curriculum of chiropractic programs is in the early stages of exploration, with consequences yet to be identified.

The ever-present concerns of the anatomy gross laboratory include the curricular time needed for students to dissect, the acquisition and management of cadavers, and potential health risks associated with chemical fixation of cadavers. As the cost of higher education continues to rise, financial responsibility of institutions is coming under increasing scrutiny. The revolving cost of acquiring

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cadavers, maintaining a functional dissection environment, and the treatment of cadaver remains are not insignificant. Additionally, finding anatomy instructors competent in dissection is becoming increasingly challenging.

Some programs have found prosections or plastination of specimens to be equally effective in conveying anatomical knowledge. These modalities are particularly suited to a system-based approach of teaching anatomy, require fewer cadavers, and allow for similar exposure to information with less course time.[1] However, prosections and plastinations still require the expense of maintaining a gross laboratory and expose students and faculty to chemical fixatives. At our institution, instructors prepared prosections for study and comparison while students performed supervised, limited dissections.

Programs seeking to remove cadavers completely from anatomy education have found themselves using a multifaceted approach incorporating medical imaging (ultrasound, computed tomography [CT], and magnetic resonance imaging [MRI]), palpation and examination of fellow students as "living anatomy," and clinical computer-based simulators.[4] Drawing, body paint, and art are also being integrated into some anatomy courses as programs shift toward active learning environments.[5]

As students become more technologically savvy and gadget oriented, many programs are exploring higher-tech alternatives to the traditional cadaver dissection laboratory. Myriad 3-dimensional anatomy programs and simulators have hit the market in recent years.[1] Studies evaluating their educational effectiveness are limited to specific subjects and show varied results. Hu et al[6] found that students preferred using a 3-dimensional computer model of a larynx over traditional lecture alone, but the efficacy of using the model was not superior to lecture alone. Fritz et al[7] followed the same cohort and found that both groups of students performed at a similar level when assessed 6 months after the original instruction, suggesting similar retention of material between those exposed to lecture and those who learned on the 3-dimensional computer-based model. Nicholson et al[8] found that students using a 3-dimensional computer-based ear model as part of a tutorial was superior to the tutorial alone. Lombardi et al[9] chose a broader topic and evaluated student knowledge of the cardiovascular system comparing 3 different teaching modalities: models, cadaver dissection, and virtual dissection. Although students preferred organ dissection, the group utilizing the models scored higher in physiology. Students in the cadaver dissection and in the model groups scored higher than those in the virtual dissection group in anatomy. On an accompanying attitude survey, organ dissection was more popular, as it was requested as a future activity twice as often as either models or virtual dissection.

Anatomage Inc. originated in San Jose, California, and is rapidly emerging as a leader in 3-dimensional anatomy visualization. It has been found to be useful in the education of imaging science students[10] and as an adjunct in medical school curriculums. Advantages of the table over other programs include visualization of imaging of real cadavers gained from detailed posthuminus CT scans. Three-dimensional anatomy models are also included. The tables are modeled after the size and orientation of the traditional cadaver dissection table, so the entire male or female organism can be explored in life size. Different anatomical planes are easily "dissected," and dissection can also progress superficial to deep. Systems are easily isolated, and the cadaver may be viewed in radiographic tones. Pathology examples are installed in the tables, and instructors can load customized MRI and CT images to create cases for their students. The 1st task in using Anatomage was to become familiar with the many functions and capabilities and learning to navigate the complex system.[10] However, the navigation is similar to other electronic devices, such as tablets and iPads.

Studies on the use of virtual dissection Anatomage tables in a chiropractic curriculum are nonexistent. Students enrolled in doctor of chiropractic programs are attracted by the holistic approach to health care without the use of drugs or surgery.[11] Chiropractic students tend to learn better when engaged in active learning.[12] Most prefer kinesthetic and didactic activities over traditional lecture. A change in anatomy teaching modalities brought suspicions that chiropractic hands-on learners would suffer in knowledge base when cadavers were replaced by models and virtual dissection Anatomage tables.

The hypothesis is that students learning and testing on the virtual dissection tables were expected to meet similar short-term assessment objectives as those learning and testing only on anatomical models or on models and cadavers, as assessed by lab and lecture examination scores. This retrospective study attempts to quantify the short-term consequences of phasing out cadavers to anatomical models and ultimate replacement with virtual dissection tables.

METHODS

The Life University institutional review board approved this project. The lecture and laboratory examination scores of 3 different cohorts of 1st-year chiropractic musculoskeletal anatomy students were evaluated and compared using simple analysis as well as analysis of variance (ANOVA) and independent *t* tests. All laboratory midterm examinations consisted of 20 structures tagged on the back or upper extremity that the students needed to identify. All final laboratory examinations had 20 structures tagged on the lower extremity for the students to identify. Laboratory examinations were hand graded by the instructor of the respective lab section and reported to the lecture instructor. Students in each cohort were exposed to a similar lecture format for 2 hours per week. Lecture examinations consisted of multiple-choice, matching, and true/false questions assembled and graded by the lead instructor. The written lecture examinations were of similar content and difficulty.

Lectures were given in a 2-hour block once a week for 10 weeks, with the final lecture exam given the 11th and final week of the quarter. The lecture midterm examination was usually given during week 5. Anatomy lab met twice a week, for 2 hours each session, for 10 weeks, with the

Table 1 - Laboratory Exam Scores

Cohort	Quarter	MT n^a	MT Mean	MT SD	Final n	Final Mean	Final SD
1	FA 13	105	74.1	20.32	101	76.1	17.49
	WI 14	102	78.7	16.57	100	76.5	16.67
	SP 14	139	80.2	17.14	115	71.1	17.30
	Pooled	346	77.67	18.18	316	74.57	17.33
2	FA 14	96	78.6	15.31	93	80.2	18.03
	WI 15	140	82.1	16.27	115	82.8	16.12
	SP 15	114	81.5	15.00	113	83.1	16.00
	Pooled	350	80.73	15.64	321	82.03	16.65
3	FA 15	116	80.3	12.18	113	84.6	14.81
	WI 16	162	85.4	12.25	158	86.5	12.68
	SP 16	116	89.1	10.99	116	84.8	13.98
	Pooled	394	84.93	12.31	387	85.3	13.72

[a] Note that the numbers relate to the actual number of exams taken and not the number of students.

midterm given in week 6 and the final lab examination given in week 10. This course is the 1st gross anatomy class in the curriculum and is followed by visceral gross anatomy and head and neck gross anatomy courses.

The students had equivalent prerequisite course work prior to enrollment in the course, and there were no changes in admission policy, applicant screening, or acceptance rate for students in the 3 cohorts. Cohort 1 (n = 352) included 2nd-quarter students taking musculoskeletal anatomy during the fall 2013 (n = 107), winter 2014 (n = 143), and spring 2014 (n = 102) quarters. The gross anatomy laboratory experience included 2 hours of instruction in the dry lab utilizing plastic anatomical models and 2 hours of dissection in the gross lab. Students were responsible for the dissection of the back, upper extremity, and lower extremity of 10 cadavers per quarter. A couple of cadavers each quarter were dissected by faculty as prosections for students to reference. Students also utilized a dissection guide, the instructor's weekly checklist, and anatomical atlases. The midterm and final laboratory examinations tested knowledge on cadavers only.

Cohort 2 (n = 350) included 2nd-quarter students taking musculoskeletal anatomy in the fall 2014 (n = 92), winter 2015 (n = 140), and spring 2015 (n = 114) quarters. The teaching modality included 4 hours per week of instruction in the dry lab on anatomical models and pictures from various atlases. Students were tested on anatomic models and pictures from recommended atlases (eg, Netter *Atlas of Human Anatomy*, Rohen *Color Atlas of Anatomy*). The midterm and final laboratory examinations included identification of structure on models and in atlases.

Cohort 3 (n = 393) included 2nd-quarter students taking musculoskeletal anatomy in the fall 2015 (n = 115), winter 2016 (n = 162), and spring 2016 (n = 116) quarters. Two laboratory instructional hours per week were devoted to the anatomical models, and 2 hours per week were spent exploring anatomy utilizing Anatomage 3-dimensional virtual dissection tables equipped with Invivo5 software (Anatomage, San Jose, CA). Laboratory midterm and final examinations each had 12 structures on anatomical models and 8 structures on the Anatomage table for students to identify.

RESULTS

All data were conglomerate, and exam scores were deidentified. Laboratory exam mean scores are outlined in Table 1. Lecture examination mean scores are outlined in Table 2.

The 3 quarters of students who were tested in lab solely on cadavers made up cohort 1, which had an average score of 77.7% on the midterm and 74.6% on the final laboratory examination. Lecture scores averaged 57.6% for the midterm and 64.7% for the final for cohort 1.

The following year, 3 quarters of students were tested on anatomical models and on atlas pictures and made up cohort 2. This group had a mean score of 80.7% on the midterm and 82% on the final laboratory examinations. Lecture scores averaged 58.4% on the midterm and 66.3% on the final.

The most recent triad of quarters comprised cohort 3 and were tested in the laboratory on anatomical models and on the virtual Anatomage dissection tables. For this group, the laboratory midterm mean was 84.9%, and the final mean was 85.3%. Lecture means for midterm and final were 61.5% and 60.6%, respectively.

Midterm laboratory exam scores showed a successive increase across cohorts, with those in cohort 3 who tested on the Anatomage tables averaging 4.2 percentage points above those in cohort 2, who tested on models only. The lowest-scoring cohort was tested on cadavers only, averaging 7.3 percentage points below those in cohort 3.

Final laboratory examination scores showed a similar trend, with the Anatomage group scoring 3.3 percentage points above the models alone and 10.7 percentage points above the cadaver group.

Overall, for the lab portion of the course, students in the cohort tested on Anatomage tables averaged 3.7 percentage points above those who tested on models alone and 9 percentage points above those who were tested on cadavers (Fig. 1). In our college, grade increments rise by an order of 10, with a score of 90% recorded as an A, 80% as a B, and 70% as a C. Hence, there was almost an entire grade difference between cohort 1 and cohort 3 in the laboratory course grade. The laboratory score makes up

Table 2 - Lecture Exam Scores

Cohort	Quarter	MT n^a	MT Mean	MT SD	Final *n*	Final Mean	Final SD
1	FA 13	107	59.7	20.38	96	64.7	15.20
	WI 14	103	58.7	15.63	99	64	16.56
	SP 14	143	54.3	14.41	134	65.5	16.11
	Pooled	353	57.57	16.90	329	64.73	15.96
2	FA 14	102	58.8	20.86	92	67.5	19.69
	WI 15	142	60.3	18.65	138	67.2	19.48
	SP 15	113	56.2	17.45	112	64.2	18.94
	Pooled	357	58.43	18.91	342	66.3	19.31
3	FA 15	113	56.7	13.27	114	57.8	14.41
	WI 16	162	61.3	13.75	161	62.8	15.46
	SP 16	114	66.6	13.17	115	61.3	14.95
	Pooled	389	61.53	13.92	390	60.63	15.12

[a] Note that the numbers relate to the actual number of exams taken and not the number of students.

50% of the overall course grade for musculoskeletal gross anatomy.

While lecture midterm scores showed a slight improvement between cohorts, this was not seen on final exam scores. When midterm and final scores were pooled, less than 1.5 percentage points separated the highest, cohort 2, from the lowest, cohort 3, for the average final course grades (Table 3, Fig. 2).

To look at the possible statistical significance of the scores, midterm and final data were 1st pooled for each cohort (Table 3), and then a 1-way ANOVA was performed. The results (Table 4), confirm the observation that significant improvements were seen in lab exam scores between cohorts (F [2, 2113] = 58.6, $p < .001$), while no significant differences were seen in lecture exam scores.

Looking more closely at the lab results by means of Tukey honestly significant difference ad hoc t tests, there were significant differences between cohorts 1 and 2 (t[1360] = 5.54, $p < .001$; 95% CI 3.15, 7.17), between cohorts 2 and 3 (t[1451] = 4.94, $p < .001$; 95% CI 6.98, 10.86), and between cohorts 1 and 3 (t[1442] = 4.94, $p < .001$; 95% CI 1.83 to 5.69). No t tests were performed between cohorts for the lecture scores, as no significant differences were seen on ANOVA.

DISCUSSION

Musculoskeletal gross anatomy encompasses regional anatomy of the back, upper extremity, and lower extremity. Students gain knowledge of superficial nerves

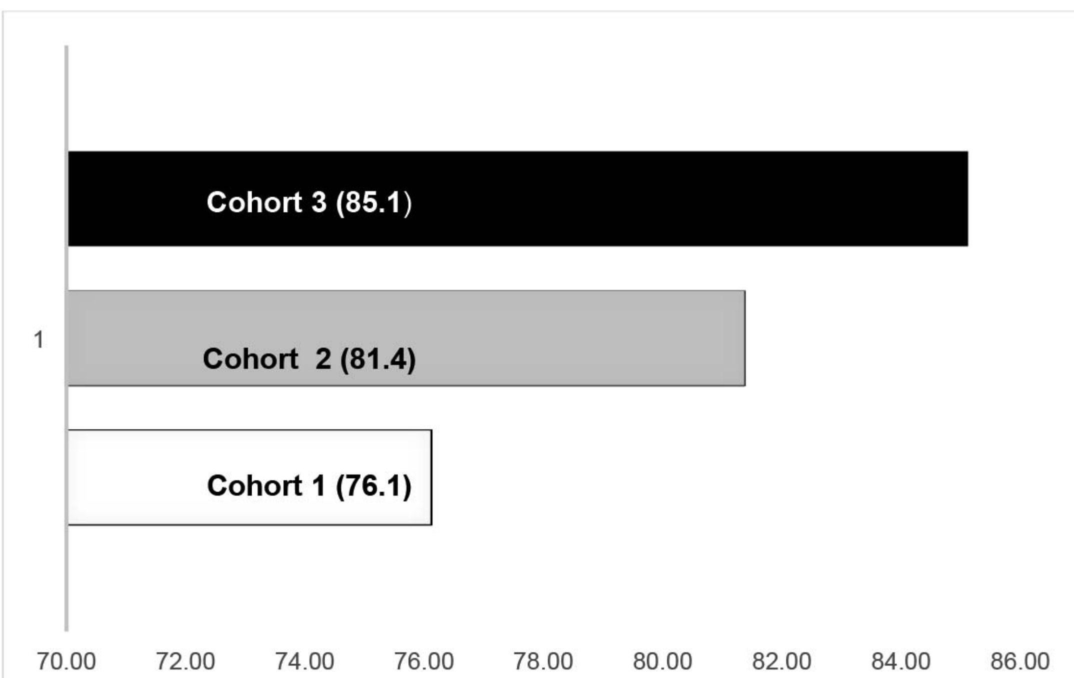

Figure 1 - Overall laboratory examination mean scores of the 3 cohorts. There was a successive increase in the score percentages of the 3 groups.

Table 3 - Pooled Laboratory and Lecture Exam Scores

Cohort	MT *n*	MT Mean	MT SD	Final *n*	Final Mean	Final SD	Pooled *n*	Pooled Mean	Pooled SD
1	346	77.67	18.18	316	74.57	17.33	662	76.19	17.78
2	350	80.73	15.64	321	82.03	16.65	671	81.35	16.13
3	394	84.93	12.31	387	85.3	13.72	781	85.11	13.03
Pooled Lecture Exam Scores									
1	353	57.57	16.90	329	64.73	15.96	682	61.02	16.45
2	357	58.43	18.91	342	66.3	19.31	699	62.28	19.11
3	389	61.53	13.92	390	60.63	15.12	779	61.08	14.53

and vessels before working into deeper muscles, nerves, blood vessels, and ligaments. While the laboratory is limited to simple identification of various structures, the lecture integrates muscle attachments, actions, and innervations. Special attention is given to the origin of a nerve from its spinal cord segments, and clinical cases and pathologies are introduced where appropriate.

The results of our evaluation of the average grades earned on laboratory and lecture examination scores from the 3 consecutive academic calendar years shows successive, statistically significant increases in the laboratory mean scores from the cadavers used by cohort 1 (76.1%) to models used by cohort 2 (81.4%) and to the Anatomage virtual dissection tables used by cohort 3 (85.1%). This could be due to many contributing factors.

In the gross dissection cadaver lab, students had the advantage of seeing and feeling actual muscles, nerves, and vessels. These structures could be traced distally as students explored the course and branches of each nerve and vessel in relationship to the muscles and skin innervated and supplied along the way. Students could appreciate degenerative conditions, pathologies, and anomalies (Fig. 3). Many hypotheses were discussed as to how each cadaver's anatomy adapted to the stresses of their life and the ultimate cause of death of the individual.

Lower laboratory scores in the cadaver cohort may be attributed to a lack of sufficient laboratory class time to dissect and learn the individual characteristics of each of the 10 tested cadavers. Two of the 10 cadavers were instructor-prepared prosections for study, comparison, and examination, while students performed supervised dissections on the other 8 cadavers. As this was the students' 1st gross anatomy course, dissection skills were those expected of novices. Students may have spent more time focused on getting the dissections accomplished and devoted less time to memorizing the foundational information. As the quarter progressed, students became less eager to participate in dissection as they scrambled to absorb the overwhelming amount of information. Additionally, many students were reluctant to attend extra lab sessions in the gross anatomy lab due to noxious fumes or a discomfort of working on the deceased.

When it came to test on the cadavers, anatomical variants as well as inconsistent quality of dissected structures made it challenging for instructors to clearly tag testable material. As dissection proceeded deeper, the superficial structures were more difficult to tag. The

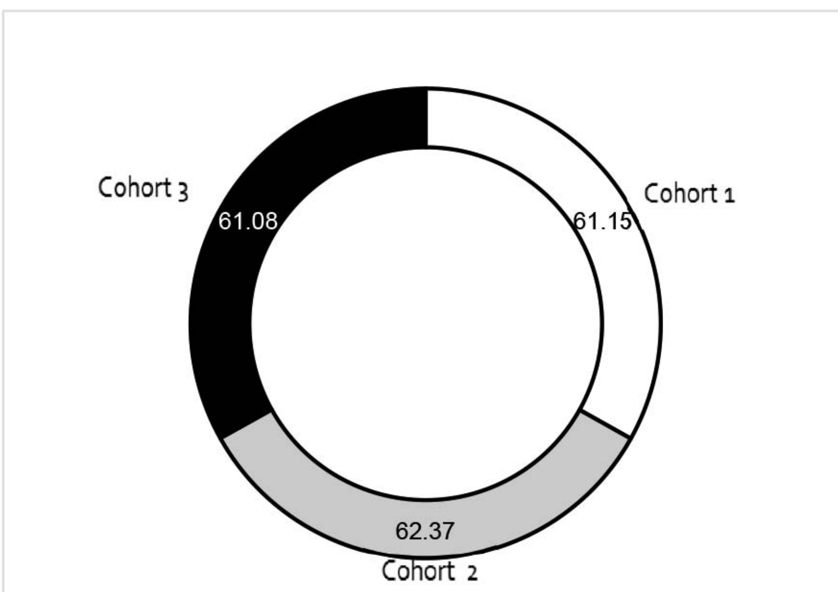

Figure 2 - The lecture examination mean scores of the 3 cohorts. There were no significant differences between the score percentages of the 3 groups.

Table 4 - ANOVA Results

	SS	*df*	MS	*F*	*p*
Lab					
Between	28,578.73	2	14,289.36	58.50	0
Within	515,671.29	2111	244.28		
Total	544,250.026	2113			
Lecture					
Between	712.9226	2	356.46	1.27	.28
Within	603,758.8501	2157	279.91		
Total	604,471.7728	2159			

pinning of poorly dissected or partially destroyed structures on examinations likely contributed to the lower examination scores earned by the 1st cohort of students.

Students in cohort 2 used primarily plastic anatomical models in their gross laboratory. Plastic models are stiff, so tactile input was limited. Spatial relationships were more challenging to discern and the courses of nerves and vessels difficult to trace. Additionally, models were simplified and lacking the detail needed for this level of education (Fig. 4). As a result, instruction was supplemented with anatomical atlases, the course text, and videos of cadaver dissection. Students could prepare using resources at home or in the library and did not need to spend hours in a noxious environment dissecting and learning variants of different cadavers. The memorization of unchanging structures came quicker, and testing for the laboratory examinations was limited to structures available on the models or in the studied atlases. As a result, instructors could tag more clearly. Vessels and nerves on models are color coded, so students no longer had to guess if the structure they were asked to identify was a nerve, an artery, or a vein. The lecture scores for this cohort were marginally higher than for either the cadaver or the virtual dissection groups. This may be due to more available time to focus on the lecture specific information, such as muscle

Figure 3 - Four different areas of the prosected cadavers. (A) Posterior view of the suboccipital region showing the atlas with symmetrical complete bilateral dorsal and lateral arcuate foramina. (B) Superior view of cross section at the level of the foramen magnum, showing the superior articular surface of atlas and cross section of medulla oblongata. (C) Posterior view of the caudal aspect of the spinal canal showing the conus medullaris and the cauda equina of the spinal cord. (D) Anterior view of the axilla after removal of the pectoralis muscles and clavipectoral fascia showing the relationship of various components of brachial plexus to axillary artery.

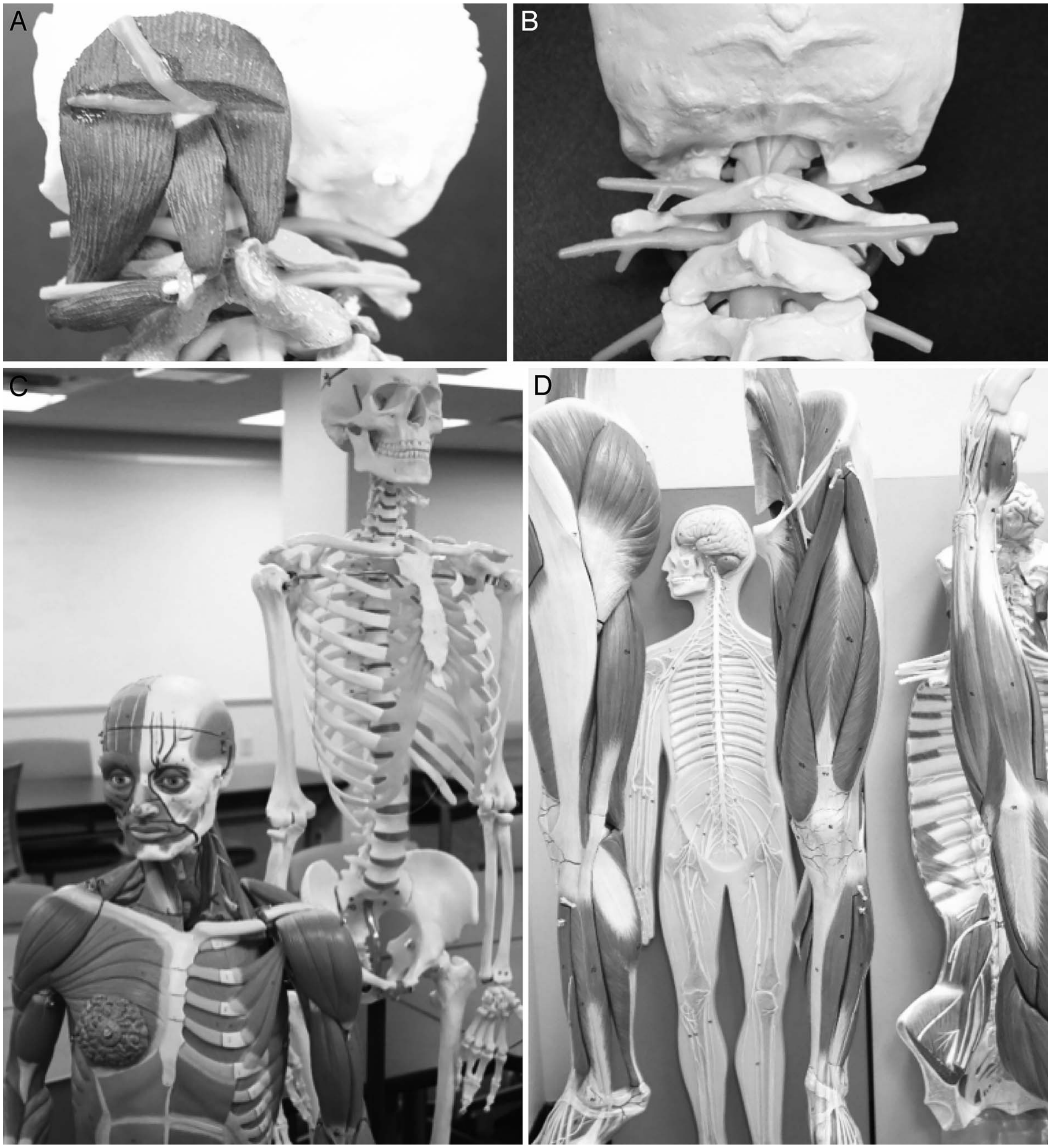

Figure 4 - Several different models representing different areas of the body. (A) Posterior view of the suboccipital region with muscles of the suboccipital triangle and C2 dorsal ramus. (B) Posterior view of the upper cervical area showing the relationship of dorsal arch of the atlas to the vertebral artery and C1–C2 dorsal rami. (C) Anterior view of a skeleton and a torso showing bones and muscles of the anterior, upper parts of the body. (D) Several models in different views showing muscles of the lower limb and spinal nerves.

function and clinical applications, as these students were not dissecting or learning a new software program.

Students of cohort 3 used the Anatomage virtual dissecting table in addition to the anatomical models. The Anatomage table (Fig. 5) provided more detail of the structures and demonstrated topography as well as depth of the structures. Students could select any structure of the body, such as a particular muscle, nerve, ligament, or bone, and observe it in multiple 3-dimensional views by highlighting and rotating it in any direction individually or as a part of the body as displayed in anatomical position. Images were clear, color coded, and unable to be destroyed by inexperienced dissection. As a result, the laboratory exam format was less subject to the pinning or tagging errors experienced by the cadaver dissection cohort. The students were able to easily navigate the Anatomage table

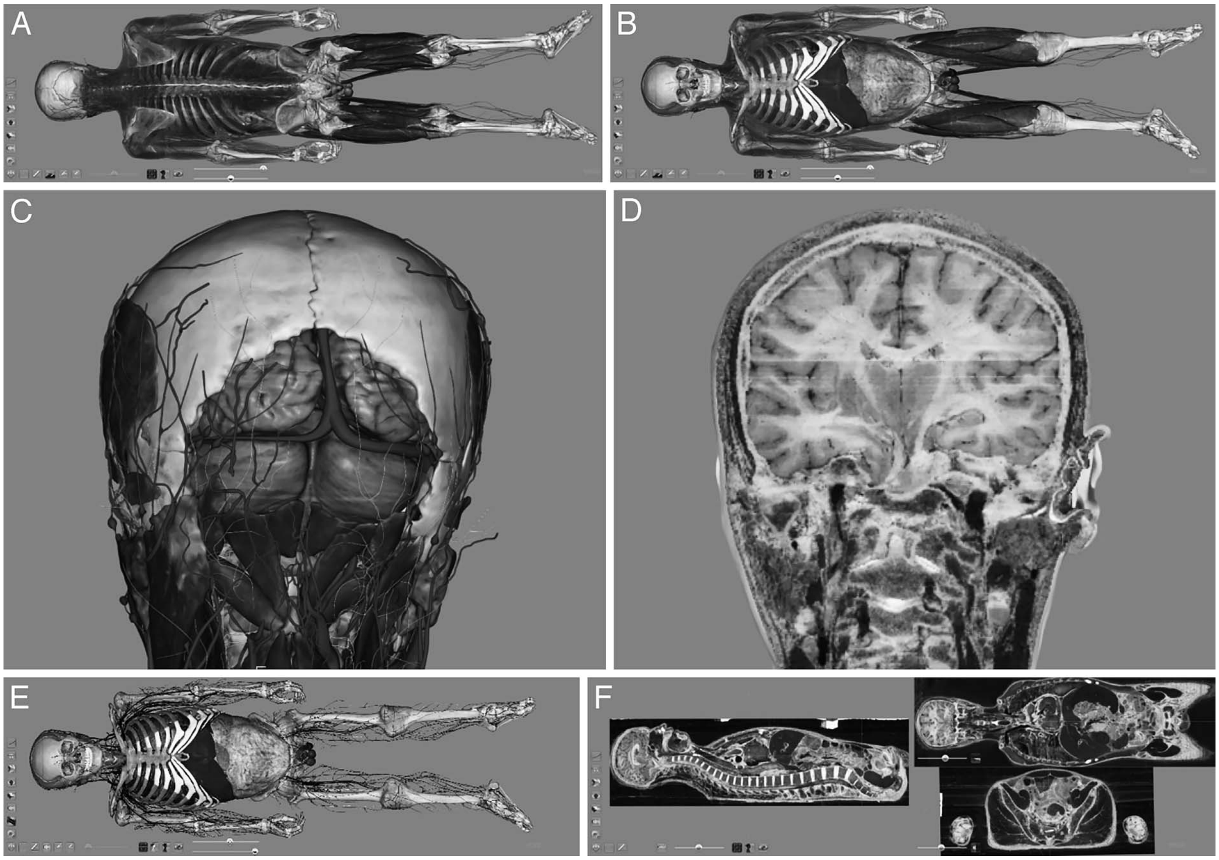

Figure 5 - Several different digital views of a full-body cadaver on the Anatomage table. (A) Posterior digital view of the deep back, gluteal, and thigh areas of the body. Reproduction of image with permission of Anatomage Inc. (B) Anterior digital view of the same body in Figure 5A. Reproduction of image with permission of Anatomage Inc. (C) Posterior digital view of the suboccipital region of the same body in Figure A with associated muscles. Reproduction of image with permission of Anatomage Inc. (D) Coronal section through the head and upper cervical area of the same body in Figure 5A, showing digital images of the brain, atlanto-occipital, and atlanto-axial joints. Reproduction of image with permission of Anatomage Inc. (E) Anterior digital view of the same body in Figure 5A, showing some abdominal viscera as well as nerves and vessels of the head, neck, and extremities. Reproduction of image with permission of Anatomage Inc. (F) This figure illustrates scanned cadaveric images of various body structures in 3 different plans; sagittal, coronal, and horizontal sections of the same body in Figure 5A. Reproduction of image with permission of Anatomage Inc.

functions; the learning curve was small, as these functions were similar to tablets and iPads. However, in 2015, Custer and Michael[10] discussed that some students had a greater learning curve for navigation of the Anatomage table. Introduction of new technology may increase students' cognitive load; however, students in cohort 3 appeared to process and function without extraneous cognitive load. The data show that they performed better than the other 2 cohorts. The images were scanned using anatomical position, so access to the axillary region was limited due to the inability to abduct the arm and stretch out nerves and blood vessels. Although 3-dimensional, the virtual dissection table is still a conglomeration of images that cannot be palpated or explored using tactile senses. The program does have the capability of loading different curricula, subjects, and pathologies; however, students were limited by time and could be exposed to only a few different subjects. Hence, an appreciation of anatomical variants and adaptations was not fostered. Testable images on the virtual dissection tables for many labs were initially limited to muscles. Vessels and nerves were still tagged on plastic models. As teaching faculty became more experienced in navigating the system, more varied structures became testable. This was a sampling of scores from students in the early phases of faculty being trained in teaching and testing using the Anatomage tables and Invivo 3 and 4 software.

Due to the inherent complexity of each cadaver, testing on cadavers is intrinsically more challenging than testing on consistent, studied images, be they plastic anatomical models, atlas pictures, or 3-dimensional computer images. This is the most viable explanation for the lower laboratory scores earned in the cadaver cohort. The lack of variability in lecture scores suggests that baseline anatomical knowledge and comprehension was consistent regardless of the methodology used to teach the gross anatomy laboratory (Tables 1 to 4).

Currently, the Anatomage table 5 is the most advanced anatomy visualization system in teaching the anatomy of the human body. Although there are some published abstracts and full papers regarding the use of the Anatomage in various anatomy courses, there is no other similar study to ours in the field yet to compare and discuss these results with. Most studies agree that a multifaceted approach to teaching and learning the subject of gross anatomy is ideal. As Anatomage continues to evolve even more usable features, such as the recent update featuring a model with abducted arms and the ability to change the background color, it will likely gain further popularity and precipitate more studies as to its effectiveness in teaching human anatomy in the chiropractic profession.

The plan will be to continue using the Anatomage tables and the plastic models for future studies to assess the long-term retention of information by comparing lab examination scores to national board examination scores.

CONCLUSION

Students utilizing combined Anatomage tables and models scored higher on laboratory examinations than students testing on models only or cadavers only. A similar testing competency in lecture examinations was observed, suggesting a possible change in laboratory examination difficulty between the cohorts but a similar knowledge base. Further studies are warranted to evaluate the long-term retention of student knowledge in anatomy following these cohorts with their respective laboratory experience.

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The authors have no conflicts of interest to declare relevant to this work.

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Concept development: SA, EP. Design: SA, AG, EP. Supervision: SA. Data collection/processing: SA, RH. Analysis/interpretation: SA, RH. Literature search: SA, AG, EP. Writing: SA, AG, EP. Critical review: SA, AG, EP.

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