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The Journal of Teaching and Learning Resources

Original Publication

OPEN ACCESS

The Clinical Anatomy and Imaging Laboratory: Vertical Integration in the Preclerkship Curriculum

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Citation: Barry DS, Dent JM, Hankin M, et al. The Clinical Anatomy and Imaging Laboratory: vertical integration in the preclerkship curriculum. *MedEdPORTAL*. 2019;15:10824. https://doi.org/10.15766/mep_2374-8265.10824

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All appendices are peer reviewed as integral parts of the Original Publication.

Abstract

Introduction: As medical schools implement integrated curricula, anatomy education especially has experienced increased pressure to make foundational content clinically relevant. We designed a novel type of integrative anatomy laboratory experience where students could use foundational anatomy concepts in concert with modern imaging/diagnostic techniques to enhance important clinical concepts. **Methods:** We selected a process called Lesson Study to develop the multidisciplinary Clinical Anatomy and Imaging Laboratory (CAIL) in the cardiovascular and gastrointestinal systems. We utilized soft-embalmed cadavers extensively for their highly realistic tissue appearance and texture, which allowed instructors and students to perform a wide array of procedures in case-based scenarios similar to practicing clinicians. We conducted field observations of participating students, focus-group discussions, and knowledge-based exams to examine efficacy of the CAIL. **Results:** Approximately 150 first- and second-year students participated in each of the CAIL activities on an annual basis. Most focus-group participants felt the CAIL was a great learning experience. They commented on how the lab provided relevance to anatomy knowledge and helped integrate prior classroom learning more deeply. Instructors noted that students asked more advanced, clinically relevant questions than in a typical anatomy lab. Knowledge improved significantly after the CAIL, although it is unclear if this translates to summative exams. **Discussion:** The CAIL creates a unique learning experience where students use prior foundational anatomy knowledge in conjunction with modern imaging and diagnostic techniques to reinforce important clinical concepts. We have continued to integrate CAIL experiences into more clinical systems in our medical school curriculum.

Keywords

Simulation, Anatomy, Gross Anatomy, Cardiology, Gastroenterology, Cardiovascular Medicine, Lesson Study

Educational Objectives

By the end of this activity, learners will be able to:

1. Identify anatomical landmarks associated with common cardiovascular and gastrointestinal procedures.
2. Integrate anatomy knowledge to help perform diagnostic and therapeutic medical procedures on a soft-embalmed cadaver while recognizing potential procedural complications.
3. Practice clinical procedures related to cardiovascular and gastrointestinal emergencies on cadaveric specimens.
4. Experience hands-on faculty instruction in a small-group simulation and anatomy lab setting.
5. Demonstrate how ultrasound imaging relates to external and internal anatomic landmarks.

Introduction

An essential goal of anatomy education in the modern medical curriculum is for students to acquire foundational knowledge on which they can build clinical reasoning skills to ultimately diagnose and treat patients. As medical schools create and implement integrated curricula, the lines between pre- and postclinical training have begun to blur, calling for increased clinical education early in medical school. Anatomy education has been continually under pressure to identify foundational content and make it more clinically relevant within the constraints of overall reduced anatomy teaching hours. Medical schools nationally are struggling to find solutions to this challenge.

The integrated 18-month preclerkship curriculum at the University of Virginia (UVA) School of Medicine is divided into courses, which are organized by body systems, varying in length from 4 to 9 weeks. Laboratory instruction in gross anatomy occurs in seven of the 11 body system courses. Active dissection occurs in some courses, but in others, the anatomy lab experience consists of students examining prosections and plastic models and interacting with anatomy software. With limited exposure to gross anatomy, students have traditionally performed poorly on anatomy exam questions. Furthermore, in weekly focus-group sessions, students have discussed difficulty in bridging the gap between the anatomy laboratory experience and the clinical knowledge they were gaining in other areas of the curriculum.

Early research has demonstrated that incorporating hands-on training using lightly embalmed cadavers into a traditional anatomy curriculum improves satisfaction, confidence, and knowledge.[1] Dissection-based procedural training with dissection models has been shown to enhance anatomy learning in medical students.[2] Using lightly embalmed cadavers as simulated patients also improves feedback and, potentially, performance among physician assistant students learning knee aspirations.[3] There has been no work published in *MedEdPORTAL* that utilizes soft-embalmed cadavers for integrating clinical anatomy and imaging or a similar model of teacher professional development to create learning experiences for medical students.

We sought to expand the field and address prior challenges by designing a novel type of integrative anatomy laboratory exercise using a clinical scaffold that occurs after the traditional series of labs within a systems-based course. We hoped to highlight for students the importance and relevance of anatomy to every modern imaging and procedural technique in use today. Our goal was to create a laboratory experience in which medical students could use foundational anatomy concepts learned in previous anatomy labs in concert with modern imaging/diagnostic techniques to reinforce and enhance clinical concepts taught in lectures and small-group sessions.

Methods

We selected a process called Lesson Study to develop the initial multidisciplinary Clinical Anatomy and Imaging Laboratory (CAIL) in the second-year medical school cardiovascular (CV) system course. Lesson Study is a model of professional development for educators whereby research lessons are developed, observed, and redesigned in a collaborative manner.[4,5] The CAIL concept was then later expanded to include the first-year gastrointestinal (GI) system course. We utilized soft-embalmed cadavers extensively for their highly realistic tissue appearance and texture,[6] which allowed the instructors and students to perform a wide array of procedures similar to practicing clinicians.

At each station in the CAIL, students interacted with a soft-embalmed cadaver (a fresh cadaver could be a lower-cost alternative), a formalin-embalmed cadaver, a live patient volunteer, simulation models, organ specimens, and/or pathology specimens to review clinically relevant anatomy, discuss diagnoses, and practice medical procedures (Appendix A: List of Equipment, Appendix B: Station Maps). An anatomist, clinician, and/or a teaching assistant facilitated the interaction at each station. System leaders personally oriented new personnel to the key teaching points at each station before the laboratory. For procedural stations, personnel with clinical experience using the equipment were selected when available. We describe the CV and GI CAIL activities in detail below. Students received the materials (Appendix C: Student Summary CV, Appendix D: Student Summary GI) describing the laboratory cases 1 week before the laboratory (per institutional policy) and were encouraged to review them the night before the session, along with prior class textbook reading assignments at their discretion.[7-9]

Cardiovascular CAIL

The CV CAIL occurred 3 weeks into the 4.5-week CV system course in order to allow students to have an adequate foundation of knowledge to build upon during the session. The lab followed a hypothetical patient through a diagnosis of aortic stenosis by transthoracic echocardiography (TTE) and then transesophageal echocardiography (TEE), preoperative cardiac catheterization, aortic valve replacement (AVR), and postoperative pericardial tamponade. Each clinical vignette correlated with a station in the lab (Appendix E: Facilitator Guide CV). Half of the second-year class of approximately 150 students participated in the 2-hour lab at one time. The 75 students were divided into five small groups and rotated through each station sequentially every 20 minutes.

CV Station 1. Transthoracic echocardiography: We recruited three volunteers to serve as patient models in a clean room adjacent to the anatomy lab. An emergency medicine attending and two cardiac sonographers served as teaching faculty. Three standard CV ultrasound machines were used to acquire images. Students were split up into three groups where the teaching faculty focused on how to acquire basic parasternal and apical echocardiography views, with special emphasis on the relationship between chest surface anatomy, cardiac views, and valve anatomy. We encouraged each student to try to acquire images to demonstrate how ultrasound probe orientation related to observation of internal structures.

CV Station 2. Transesophageal echocardiography: The scenario patient was referred for TEE to better evaluate valve anatomy. A cardiology attending utilized one to two TEE simulators to demonstrate the various standard views while emphasizing the difference in anatomic orientation compared to the TTE station. Students then took turns using the simulators and identifying anatomic structures. Of note, this station replaced a prior final trauma station with a formalin-preserved cadaver where the patient had had a car accident and an aortic injury, as we felt it was a better match for our course materials, equipment availability, and instructor expertise. However, the trauma station remains an option if no TEE simulator is available.

CV Station 3. Cardiac catheterization: The scenario patient was referred for cardiac catheterization to rule out coronary artery disease prior to surgery for severe aortic stenosis. We employed a fourth-year medical student or cardiology fellow at this station and obtained expired coronary catheters and guidewires from the catheterization laboratory. A softembalmed cadaver was used to pass coronary catheters from the upper and lower extremities to the ascending aorta. During the session, students reviewed the arterial anatomy from the sheath insertion sites to the ascending aorta, as well as potential complications from each approach. Computer monitors around the station displayed static and video images of coronary angiograms.

CV Station 4. Surgical aortic valve replacement: After completing preoperative evaluation, the scenario patient elected to undergo open AVR. A cardiothoracic surgery resident or fellow worked with an anatomist before the lab to dissect a soft-embalmed cadaver to provide a realistic simulation of the operative view during open heart surgery. A video camera projected the operative field onto a large monitor to enable more students to clearly see the cadaver. The cardiothoracic surgery resident/fellow then reviewed the anatomy of the chest wall, pericardial and pleural spaces, epicardium, and coronary vessels with students. The locations for cannula placement for cardiopulmonary bypass were also discussed, with sample cannulas available for the students to examine.

CV Station 5. Cardiac tamponade and pericardiocentesis: During recovery from surgery, the scenario patient experienced dyspnea and was diagnosed with a pericardial effusion. A cardiology attending and fellow (or fourth-year student) began by discussing in a question-and-answer format with the students the physiology behind cardiac tamponade. The students then divided into two groups to visit each substation. At one substation, we used a formalinpreserved cadaver to demonstrate the anatomy of the pericardium and the locations of pericardial reflections. We discussed the approaches to draining a pericardial effusion and the potential complications of the procedure. At the second substation, we used a pericardiocentesis simulator manikin in combination with an ultrasound machine to allow one student from each group to practice the procedure with ultrasound guidance and gain an understanding of the relationship between anatomic landmarks and the desired approach for pericardial drainage. A computer monitor displayed sample static echocardiogram images of no, small, and large pericardial effusions. The two substations integrated the gross, surface, and ultrasound anatomy related to pericardiocentesis.

Gastroenterology CAIL
The gastroenterology CAIL stations were developed in a slightly different format. While in the CV CAIL experience, instructors chose to develop the stations with one cohesive case (or story) for students to follow, the gastroenterology session developers determined that four separate minicases for the eight stations would better fit their material. Students rotated between these eight shorter stations for the duration of the 2-hour laboratory exercise (Appendix F: Facilitator Guide GI).

GI Case 1, Station A. Gastric histopathology: Students reviewed pathology images of peptic ulcer disease as well as normal gastric histology with a histologist. Based on an image, we asked students to identify the cell type, give its anatomic location in the stomach, and describe its function.

GI Case 1, Station B. Acute upper GI bleeding: The scenario patient presented with a massive upper GI bleed. A gastroenterology fellow and attending, in conjunction with a surgical technician, used a soft-embalmed cadaver to demonstrate upper endoscopy, and students were each given a chance to drive the gastroscope through the stomach into the duodenal bulb. An anatomy faculty member reviewed the vascular supply of the stomach and duodenum on a dissected formalin-preserved cadaver. We also integrated discussion on management of upper GI bleeding, including endoscopic therapy as well as angiography requiring knowledge of the celiac axis and its branches, under the lead of an interventional radiology fellow.

GI Case 2, Station A. Laparoscopic appendectomy: At this station, the scenario patient presented with an acute abdomen with signs and symptoms consistent with a perforated appendix. Students observed while two surgeons demonstrated an exploratory laparoscopy on a soft-embalmed cadaver. The surgery instructors led a discussion on the differential diagnosis, workup, and management of a patient presenting with an acute abdomen. They also laparoscopically reviewed relevant anatomy in the soft-embalmed cadaver.

GI Case 2, Station B. Acute abdomen radiology: Using the clinical scenario of a patient presenting with an acute abdomen, a radiologist reviewed relevant CT scan and X-ray images with students. For a given etiology of acute abdomen, we asked students to identify the classic radiological findings.

GI Case 3, Station A. Liver biopsy: A gastroenterologist presented a case of a patient with abnormal liver function tests requiring liver biopsy. We used a formalin-preserved cadaver to demonstrate the anatomical location of the liver, proper technique of a liver biopsy, and potential procedural complications.

GI Case 3, Station B. Hepatic gross and histological correlations: A pathologist showed students gross and histological hepatic specimens along with a panel of blood work. Working in small groups, the students filled in a chart of diagnoses and matched them with the correct specimens.

GI Case 4, Station A. Oral gastric and Blakemore tube placement: The case scenario described a liver disease patient suffering from an upper GI bleed, likely originating from the stomach. Each student passed an oral gastric tube on a soft-embalmed cadaver.

GI Case 4, Station B. Blakemore tube placement and portal hypertension vascular review: Fourth-year students then demonstrated the technique of passing a Blakemore tube for tamponade of esophageal varices on a formalin-preserved cadaver with a dissected stomach window that allowed visualization of inflation of the gastric balloon used in stabilization of acute bleeding. Anatomy teaching faculty reviewed with students the vasculature involved in portal hypertensive bleeding that can occur in liver disease patients. We dissected a formalin-preserved cadaver to highlight these blood vessels and their confluences.

Assessment

We hypothesized that these CAIL activities would increase student knowledge of anatomic structures and concepts, improve student interest in anatomy, and enhance the clinical application and relevance of prior anatomy knowledge. In order to assess the efficacy of this intervention, we first conducted field observations of the students participating in the CV and gastroenterology laboratories. Detailed notes were collected, with specific attention to student-student interactions, as well as the questions that students were raising with each other and the station instructors during the CAIL sessions. After the laboratory was completed, station leaders participated in oral and written sessions to collect their reflections about the laboratory session.

After the CV CAIL, we conducted three focus groups with students in order to gain perspective on the students' experiences and the CAIL's perceived contributions to their learning of CV anatomy and clinical medicine. Twenty student volunteers participated in focus groups (six to eight students per group). Focus groups were audio recorded and later transcribed for analysis. Transcripts of focus groups were uploaded into the qualitative data analysis software program QST NVivo 10 in order to process, organize, search, and code the data.[10] First-level coding was completed to sort segments of data, guided by our theoretical framework and focus-group protocol.[11] After the initial coding was completed, the data were reviewed and discussed among the research team and sorted further using an open-coding technique to develop themes.

To assess student understanding of integrated clinical concepts, we administered a pre- and post-CAIL knowledge exam to students participating in the gastroenterology CAIL. The 12-question voluntary multiple-choice quiz was developed by two faculty members and available to students 24 hours before and after the CAIL experience. It did not contribute to students' grades in the GI system. The questions are not published here due to their ongoing use for assessment purposes at our institution. They centered on the clinical scenarios explored during the CAIL, with a specific emphasis on diagnostic and treatment options, including complications, correlated to anatomy. The UVA Institutional Review Board determined that our project met criteria for exemption.

Results

Approximately 150 first-year (for GI) and 150 second-year (for CV) medical students participated in the CAIL activities on an annual basis as part of their preclerkship curriculum at UVA. For the purposes of this publication, data were collected during the first academic year of implementation. The CAIL activity was received well by and garnered excellent feedback from students and instructors. After the first year of implementation, the majority of students in focus-group sessions reported that the CV CAIL activities were a great learning experience. Major themes included the opportunity to experience hands-on practice, consolidate and contextualize information, interact with a variety of instructors with different clinical perspectives, and use anatomy knowledge in a clinical context. Illustrative quotes from students categorized by theme included the following:

- Hands-on practice:
  - "I had a really tough time, prior to class, because you see an image of an echo and you are supposed to know different ventricles and atria. Then you are actually holding the probe, and you can manipulate it, then you understand the axis that you're actually pointing a probe at, as opposed to a picture of someone holding a probe and that picture next to it."
  - "Getting hands-on experience was so valuable. Getting more comfortable with obtaining the views at least in regards to the echo, because that's something we will probably have to do in the future."

    - “I definitely felt more ready after practicing in this lab to identify structures. . . . honestly, it wasn’t very easy for me to relate a 2D image to a 3D image before lab. But, afterwards I felt like I could do it on the exam if asked.”
- Consolidate and contextualize information:
    - “Nothing makes complete sense until the end when you finally put it all together, but I felt like I walked into this and I didn’t know a lot, so I was struggling through, but by the end of it I was much more prepared to study for the exam.”
    - “I was further interested in the topics or information, so then I was able to review it easier and with more enthusiasm.”
    - “I think the value in it . . . clarifying the material in class, it might not clarify as much as it contextualized the usefulness of it, that you’re given a framework. It trains your mind to recall facts at the appropriate time, like when you are in a similar situation. I think that’s useful. That’s what I’m hoping for, long term memory.”
- Variety of perspectives/instructors:
    - “It was really cool to hear her talk about the surgery. I really enjoyed the chance to talk to her and learn from her.”
    - “Each station was significantly different from the previous one, which I thought was great. I thought each person that was handling the station was good about getting everyone to interact with the stations. That was really phenomenal and different from a traditional lab.”
    - “Having all the clinicians there from different fields and specialties was so valuable and efficient. They pointed out what we should be looking for as well as all the clinical correlates.”
    - “I think having your cardiologist go through and teach [anatomy] is different from having an anatomist teach you [anatomy]. They’re both very important.”
- Use of anatomy in clinical context:
    - “It seems like some of the anatomy professors like to point out really vague things that don’t really have a big clinical impact. This was the exact opposite. Everything we learned you could tell had a clinical impact and we learned how you might use it in a clinical setting. That was really important.”
    - “This was a cool bridge from the anatomy stuff that we talk about all the time, the procedures and stuff. Just things like that. It was actually cool to see it happening.”
    - “Some of it is really cool stuff, like doing echo. That was a pretty good experience. Not many medical students may have the opportunity . . . and also that open heart surgery looked so real. That was a positive experience.”
    - “The underlying anatomical relationships, like in the car accident scene. Working with the cadaver there, you got to refresh your memory of the important relationship, especially as it relates to trauma. I think that’s helpful.”

Students commented specifically about how CAIL “made basic material relevant” and “solidified conceptual knowledge and facts.” Students perceived that “they had to think in a different way in the lab.” They also reported that the laboratories provided an enhanced learning environment to integrate the classroom material with their anatomy studies. The format of the laboratory allowed students to consolidate information in a practical way. In particular, students valued not only the hands-on experience that CAIL provided but also the explicit connection to their classroom learning.

However, students did mention that there might not be direct gains on their summative written examinations from the experience. For example, one student mentioned that the labs were “very cool and good for overall knowledge base. Probably going forward in the clerkships they will be very helpful, but don’t think it was super high yield for the summative.” Students did especially value though the experience of using both the simulators and the ultrasound machines, commenting that these were atypical experiences for most medical students.

Session instructors noted that students asked more advanced and clinically relevant questions during the CV and GI sessions than in a typical anatomy lab. Instructor reflections and station notes provided details of these high-level clinical and procedural questions. We include examples of these interactions from CV Station 4 (surgical AVR) below.

- Student question: How do the lungs tolerate not having blood flow during cardiopulmonary bypass?
  - Instructor response: Dual circulation. Lungs receive nutrients from both the pulmonary arterial flow as well as oxygenated blood from the bronchial arteries. You will learn more in pulmonary anatomy.
- Student question: Are there surgeries where a sternotomy incision is performed but cardiopulmonary bypass is not used?
  - Instructor response: Yes, including thymectomy, sometimes pericardiectomy, and off-pump CABG [coronary artery bypass graft]—briefly discussed some of the pros/cons of off-pump CABG.
- Student question: How do you ensure that the suture lines in the aorta and atrium don't bleed after surgery? Do these areas develop aneurysms later?
  - Instructor response: Aortotomies are under highest pressure and most at risk for bleeding; use double layer closure and sometimes surgical adhesives to minimize bleeding. Can have pseudoaneurysms develop at these sites (uncommon) that may need repair, but ascending aortic aneurysms usually form by a different process. Discussed the aortopathy that can occur with bicuspid aortic valves.
- Student question: What are the neurologic consequences of cardiopulmonary bypass?
  - Instructor response: We discussed the risks of embolic events, where these originate (plaque/calcium in ascending aorta, air, clot), and how occult rate of small embolic strokes is much higher than the rate of clinically detected strokes. Overall improvements in filters and circuits have improved outcomes, and studies are ongoing to determine if newer embolic protective devices may help further limit stroke risk.
- Student question: What are the indications for transcatheter AVR (TAVR) as opposed to surgical AVR?
  - Instructor response: Discussed that TAVR is currently for higher-risk patients and that there are minimally invasive surgical options as well (between TAVR and sternotomy AVR in terms of invasiveness).

The collaborative development of the CAIL was novel to the faculty involved and afforded an opportunity for professional development within a multidisciplinary team. Students also commented on the enhanced learning environment provided by learning from a diverse team of educators.

Finally, in the GI system, 106 students (68% of the class) participated in the 12-question pre- and post-CAIL knowledge exam. There was a significant increase in performance on the post-CAIL knowledge exam ($p <$ .001). On the pretest, students answered on average 5.23 (43.6%) questions correctly (SD = 1.76). The high score was 10, and the median score 5. On the posttest, students answered on average 7.74 (64.5%) questions correctly (SD = 1.58). The high score was 12, and the median score 8.

Discussion

The CAIL activity creates a unique learning experience where students use prior foundational anatomy knowledge in conjunction with modern imaging and diagnostic techniques to reinforce important clinical concepts. The activity received very positive feedback from students and instructors. Importantly, students commented on how it provided relevance to anatomy knowledge and helped integrate prior learning. Instructors noted that questions were more clinically relevant than in a typical anatomy activity. Student knowledge also improved significantly after participation in the GI CAIL.

We have made slight modifications to the CAILs over the years based on student feedback. At some stations (such as CV Station 4), we have utilized a video camera and monitors to enable better visualization in what can often be a small, crowded space around a cadaver. We have also improved our Appendices to distinguish actual learning objectives from more advanced hands-on procedural concepts that students are expected merely to begin to learn about. Finally, since only one group can actually experience the CV CAIL in a perfectly correct order (starting with Station 1 and ending at Station 5), we have emphasized to station instructors to make note of this situation and provide additional brief clinical context with the first group of the day.

Limitations of our evaluation methods include the fact that the knowledge exam and participation in the focus groups were voluntary, which could have led to students who felt more knowledgeable or positive after the lab being more likely to participate. We also did not test specifically for long-term knowledge retention. We do not have data to support whether or not the CAIL improves summative exam scores, although some student feedback suggests it is unlikely to do so given the multiple learning activities during the entire curriculum. For example, the CV system encompasses over 80 hours of sessions (with yearly modifications) covering a diverse array of topics. We would not expect to see a statistically significant change in summative exam performance from one year to the next due to a single 2-hour laboratory exercise, nor was this the ultimate aim of the exercise. We consider some of the biggest benefits of the CAIL format to be the applicability it provides to anatomy material and how it brings together instructors with various backgrounds in activities that help integrate prior knowledge to make it more clinically relevant to students who have not yet entered their clerkship year.

We believe that this type of laboratory is generalizable and can be integrated positively into the curricula of other medical schools based on the increasing availability of soft-embalmed cadaveric specimens and simulation equipment. Following the general format we present, the CAIL activity could be individually customized to the available resources at each institution with an expected similar outcome for students. Institutions can either choose to exactly replicate our sessions or instead use the integrated anatomy-imaging framework as a template for novel laboratories incorporating their regional expertise and equipment.

In the future, we plan to continue to integrate CAIL experiences into more clinical systems in our medical school curriculum. We have recently developed a CAIL for the pulmonary system, as well as an alternative-format CAIL experience for the musculoskeletal and integumentary system. Finally, we are in the process of creating a pelvic anatomy CAIL.

While the laboratories are somewhat labor intensive to develop, the iterative nature of this development process, involving many people as experts in their disciplines, has allowed for varied groups of educational professionals, physicians, and basic scientists to create unique CAIL sessions that fit into their systems. This collaborative aspect of CAIL development and integration has proved to be an extremely positive, value-added, and unique learning experience for our preclerkship students.

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Disclosures
None to report.

Funding/Support
None to report.

Ethical Approval
The University of Virginia Institutional Review Board approved this study.

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Received: December 3, 2018 | **Accepted:** March 29, 2019 | **Published:** May 15, 2019