The role of ultrasound is expanding in both clinical medicine and medical education. For patient care, there is a growing emphasis on using ultrasound at the point of care to help diagnose and manage patients (9). For undergraduate medical education, ultrasound is becoming more widely incorporated into the basic science years, especially in anatomy (6, 12). Studies have shown that medical student perceptions about the use of ultrasound to teach anatomy are positive (7). It appears that even with a short ultrasound course, students can learn how to obtain adequate cardiac images and correctly identify anatomic structures (14). Griskaitis et al. (4) found that ultrasound can be as effective as prosection for teaching cardiac anatomy.

There is less in the literature about using ultrasound to teach physiology. In one study (1), medical students reported cardiac ultrasound was the “most significant” and “most interesting” of all the practical exercises offered in their physiology course. In another study (5) that used ultrasound to teach cardiac anatomy and physiology, 98% of the students reported that they enjoyed the course and 74% thought the course improved their understanding of cardiac physiology.

Thus, limited data show that medical student perceptions about the use of ultrasound for teaching cardiac physiology are very positive. However, there does not appear to be any significant evidence that ultrasound actually improves knowledge of cardiac physiology. The purpose of the present study was to provide an objective measure of whether ultrasound helps medical students learn cardiac physiology, specifically the nonelectrical components of the cardiac cycle.

MATERIALS AND METHODS

This study had exempt status from the Institutional Review Board of the University of South Carolina. Recruitment for the study was done by e-mail invitation to all 96 first-year medical students at the University of South Carolina School of Medicine. A total of 20 students volunteered to participate, which was a response rate of 21%. The mean age of the students was 23.7 yr. There were 10 male students and 10 female students.

The study was conducted before cardiac physiology was covered in the curriculum. Participants took a pretest on cardiac physiology to assess their background knowledge. Next, they participated in a hands-on ultrasound laboratory session. Finally, they took a posttest to assess for improvement.

Participants had 15 min to complete the pretest, which consisted of nine study questions and five filler questions (APPENDIX). The study questions were multiple-choice questions about the nonelectrical components of the cardiac cycle based on the diagram shown in Fig. 1. These study questions were written by a physiology department faculty member who was blinded to the specific material to be covered in the ultrasound laboratory. The filler questions were included to lengthen the test and serve as control questions. They were multiple-choice questions about topics not covered in the ultrasound laboratory, such as electrical components of the cardiac cycle, coronary blood flow, and effects of inspiration. They were written by one of the ultrasound laboratory preceptors to ensure that they did not cover material in the laboratory.

Each student individually had a single 15-min hands-on ultrasound laboratory session with one of two faculty preceptors from the Ultrasound Institute, and the determination of which preceptor taught the student was random. Each student started the hands-on session by acquiring a parasternal long-axis (PLAX) view of the heart on a standardized patient using a GE LOGIQe ultrasound unit. All students had learned the PLAX view in their anatomy course the previous semester. The preceptor decided when the student had obtained a view that clearly showed the left atrium, left ventricle, aorta, mitral valve, and aortic valve (Fig. 2). At that point, the student captured a video loop consisting of several cardiac cycles (see Supplementary Video S1 in the Supplemental Material).1 The preceptor then used this loop

---

1 Supplemental Material for this article is available at the Advances in Physiology Education website.
paired difference between pretest and posttest scores was evaluated with a particular help clarify.

3

The mean score for the pretest study questions was 4.8 of 9 points (53.3%). The mean score for the posttest study questions was 7.35 of 9 points (81.7%). The mean difference in scores between the tests was 2.55, which was significant at $P < 0.0001$.

The mean score for the pretest filler questions was 2.9 of 5 points (58.0%). The mean score for the posttest filler questions was 2.6 of 9 points (52.0%). The mean difference in scores between the tests was $-0.3$, which was not significant at $P = 0.2088$.

Five of the nine study questions showed a significant difference in the number of correct responses on the posttest compared with the pretest. These questions addressed the following topics: closure of the mitral valve ($P = 0.0110$), left ventricular end-diastolic volume ($P < 0.0001$), opening of the aortic valve ($P = 0.0114$), the second heart sound ($P = 0.0457$), and left ventricular end-systolic volume ($P = 0.0218$). The question with the biggest difference was the question addressing left ventricular end-diastolic volume. Seven students (35%) answered that question correctly on the pretest, and all 20 students (100%) answered it correctly on the posttest.

The questionnaire about the ultrasound laboratory was completed by all 20 students (Table 1). At least 95% of the students gave a positive response for each question.

Free text comments were made by 16 of 20 students. A frequent comment was that the laboratory was particularly helpful for explaining “pressure and volume relationships.” Another recurring comment was that the laboratory was especially helpful for presenting “valve opening and closure.” Students also frequently stated that they “really enjoyed” the laboratory.

DISCUSSION

The present study evaluated the impact that an ultrasound laboratory session had on students learning cardiac physiology. The type of learning assessed was acquisition and short-term retention of knowledge rather than long-term retention. The pretest served as a measure of baseline knowledge, and the

RESULTS

The mean score for the pretest study questions was 4.8 of 9 points (53.3%). The mean score for the posttest study questions was 7.35 of 9 points (81.7%). The mean difference in scores between the tests was 2.55, which was significant at $P < 0.0001$.

The mean score for the pretest filler questions was 2.9 of 5 points (58.0%). The mean score for the posttest filler questions was 2.6 of 9 points (52.0%). The mean difference in scores between the tests was $-0.3$, which was not significant at $P = 0.2088$.

Five of the nine study questions showed a significant difference in the number of correct responses on the posttest compared with the pretest. These questions addressed the following topics: closure of the mitral valve ($P = 0.0110$), left ventricular end-diastolic volume ($P < 0.0001$), opening of the aortic valve ($P = 0.0114$), the second heart sound ($P = 0.0457$), and left ventricular end-systolic volume ($P = 0.0218$). The question with the biggest difference was the question addressing left ventricular end-diastolic volume. Seven students (35%) answered that question correctly on the pretest, and all 20 students (100%) answered it correctly on the posttest.

The questionnaire about the ultrasound laboratory was completed by all 20 students (Table 1). At least 95% of the students gave a positive response for each question.

Free text comments were made by 16 of 20 students. A frequent comment was that the laboratory was particularly helpful for explaining “pressure and volume relationships.” Another recurring comment was that the laboratory was especially helpful for presenting “valve opening and closure.” Students also frequently stated that they “really enjoyed” the laboratory.

DISCUSSION

The present study evaluated the impact that an ultrasound laboratory session had on students learning cardiac physiology. The type of learning assessed was acquisition and short-term retention of knowledge rather than long-term retention. The pretest served as a measure of baseline knowledge, and the

RESULTS

The mean score for the pretest study questions was 4.8 of 9 points (53.3%). The mean score for the posttest study questions was 7.35 of 9 points (81.7%). The mean difference in scores between the tests was 2.55, which was significant at $P < 0.0001$.

The mean score for the pretest filler questions was 2.9 of 5 points (58.0%). The mean score for the posttest filler questions was 2.6 of 9 points (52.0%). The mean difference in scores between the tests was $-0.3$, which was not significant at $P = 0.2088$.

Five of the nine study questions showed a significant difference in the number of correct responses on the posttest compared with the pretest. These questions addressed the following topics: closure of the mitral valve ($P = 0.0110$), left ventricular end-diastolic volume ($P < 0.0001$), opening of the aortic valve ($P = 0.0114$), the second heart sound ($P = 0.0457$), and left ventricular end-systolic volume ($P = 0.0218$). The question with the biggest difference was the question addressing left ventricular end-diastolic volume. Seven students (35%) answered that question correctly on the pretest, and all 20 students (100%) answered it correctly on the posttest.

The questionnaire about the ultrasound laboratory was completed by all 20 students (Table 1). At least 95% of the students gave a positive response for each question.

Free text comments were made by 16 of 20 students. A frequent comment was that the laboratory was particularly helpful for explaining “pressure and volume relationships.” Another recurring comment was that the laboratory was especially helpful for presenting “valve opening and closure.” Students also frequently stated that they “really enjoyed” the laboratory.

DISCUSSION

The present study evaluated the impact that an ultrasound laboratory session had on students learning cardiac physiology. The type of learning assessed was acquisition and short-term retention of knowledge rather than long-term retention. The pretest served as a measure of baseline knowledge, and the
posttest served as a measure of knowledge after the ultrasound session. The determination of acquisition of knowledge and short-term retention was made by comparing performance on the pretest and posttest. The significant improvement in mean scores from 53.3% to 81.7% provided evidence of learning. Specifically, the students were able to learn nonelectrical components of the cardiac cycle.

Several measures were taken to ensure that any potential difference in performance could be attributed to the ultrasound experience. One measure was blinding of the faculty members. Specifically, the preceptors teaching students were blinded to the pretest/posttest questions. This prevented the preceptors from unintentionally teaching to the answers during the laboratory session. Likewise, the faculty member who wrote the study questions was blinded to the scripted laboratory material. This prevented potential bias caused by tailoring the questions specifically to the laboratory content.

Participants were not told that the study had a pretest/posttest format. If the students had known that a posttest was to follow the ultrasound laboratory, they may have focused more intently on discovering the answers to the questions on the pretest, and this could have inflated posttest scores. By students not knowing that a posttest was to follow, the hands-on session more closely simulated a normal laboratory and the impact of such an experience.

Filler questions were incorporated into the tests to help disguise the study questions. If the pretest had consisted solely of questions based on the nonelectrical components of a cardiac cycle diagram, the students may have been able to surmise the outcome that was to be measured. This could potentially have artificially improved their performance on the posttest if they had focused more intently on discovering the answers to those particular questions during the ultrasound laboratory.

The filler questions also served as control questions since they did not address the material covered in the ultrasound laboratory. Thus, they gave a measurement of whether students could improve their scores without any intervention. The mean score for the filler questions on the pretest was 58% compared with 52% on the posttest. Thus, there was no significant difference ($P = 0.2088$) in performance on material that was not covered in the laboratory.

Another measure to ensure accuracy of any detected difference was that the preceptors did not answer any questions during the ultrasound laboratory. Since the preceptors were not aware of the particular questions on the tests, they would not know if the students were asking them for an answer to one of the test questions. This measure prevented the preceptors from inadvertently passing along answers to tests.

It should be noted that this study did not use control groups to compare ultrasound laboratory teaching to other forms of instruction. The purpose of this study was to answer the question of whether an ultrasound laboratory could be used as a vehicle to effectively teach cardiac physiology. Objectively, it did demonstrate that students can learn cardiac physiology well in a short time period through this laboratory-based method of instruction. Given this evidence, future projects could compare ultrasound with more traditional methods of instruction. Control group students could be taught via lecture or directed readings, and their performance could be compared with those taught with ultrasound. The potential of ultrasound to augment cardiac physiology education could be studied by teaching all students with traditional methods and adding an ultrasound laboratory experience for the experimental group students.

Additionally, this study did not attempt to determine the relative impact that the ultrasound images had on learning within the one-on-one laboratory sessions. However, determining the relative contribution of ultrasound was not the purpose of this study. The purpose was to see if an ultrasound laboratory could be used as an effective platform for presenting the material for the students to learn. The degree to which the ultrasound images impacted learning within the one-on-one sessions could be determined in the future by comparing performance after presenting the same material to one group using the ultrasound images and another group without the ultrasound images.

As previously noted, the study took place before students were introduced to cardiac physiology in the curriculum. Students considered the laboratory a valuable teaching tool for improving their existing knowledge of cardiac physiology. Given their very positive feedback, it is likely that an ultrasound laboratory would also be helpful as a means to clarify or...
reinforce material presented in the standard teaching format. Importantly, students considered the laboratory to be an enjoyable exercise. Thus, it would likely be well received as a supplement to material previously presented by traditional methods.

The sample size for this study was small, with only 20 students participating. It is possible that the students who volunteered for the study were more motivated learners than those who did not participate. If so, then the difference between pretest and posttest performance may have been less if a full spectrum of students participated. Despite this small size, the results were statistically significant. Thus, the study showed that ultrasound was an effective teaching tool for at least the subset of the class that participated.

This study was unique in that it helped quantify the impact that an ultrasound laboratory had on students learning cardiac physiology. Many studies on ultrasound in medical education focus on the subjective benefit of ultrasound as a teaching tool. Like those previous studies, this study also found favorable student perceptions about the use of ultrasound. Additionally, however, it provided objective evidence that students can learn cardiac physiology with the aid of ultrasound.

Ultrasound is not the only supplemental tool for teaching cardiac physiology. Specifically, there are software programs that simulate the mechanics of the cardiac cycle (2, 11, 14). The advantage that ultrasound offers over these programs is that students can simultaneously learn an imaging modality that is very valuable for patient care. Ultrasound plays a major role in the evaluation of patients with heart failure, and a greater emphasis is being placed on sound plays a major role in the evaluation of patients with heart failure, and a greater emphasis is being placed on


deCara et al. (3) have shown that medical students can assess cardiac function in a point of care fashion (8, 10). The advantage that ultrasound offers over these programs is that students can simultaneously learn an imaging modality that is very valuable for patient care. Ultrasound plays a major role in the evaluation of patients with heart failure, and a greater emphasis is being placed on the subjective benefit of ultrasound as a teaching tool. Like those previous studies, this study also found favorable student perceptions about the use of ultrasound. Additionally, however, it provided objective evidence that students can learn cardiac physiology with the aid of ultrasound.

This study provides evidence that a hands-on ultrasound laboratory can indeed help medical students learn cardiac physiology. Specifically, the laboratory helped students with the acquisition and short-term retention of knowledge of the nonelectrical components of the cardiac cycle. Ultrasound is a safe noninvasive modality that allows real-time visualization of the dynamic nature of the heart. The implication of this study is that ultrasound can be a valuable tool to enhance cardiac physiology education. Future studies are needed to assess the impact that ultrasound can have in addition to the traditional methods of teaching physiology or compared with those methods.

APPENDIX: PRETEST/POSTTEST QUESTIONS

Study Questions

Question 1. Which of the following occurs at the arrow labeled 1?
A. Ventricular diastole.
B. Closure of the mitral valve.
C. Closure of the aortic valve.
D. Opening of the aortic valve.
E. Opening of the tricuspid valve.

Question 2. The arrow labeled 2 represents:
A. Stroke volume.

B. Left ventricular end-systolic volume.
C. Left ventricular end-diastolic volume.
D. A and C are BOTH correct.
E. A, B, and C are ALL correct.

Question 3. Which of the following occurs at the arrow labeled 3?
A. Closure of the mitral valve.
B. Closure of the tricuspid valve.
C. BOTH A and B are correct.
D. NEITHER A nor B is correct.

Question 4. The arrow labeled 4 represents:
A. Aortic diastolic pressure.
B. Peak atrial systolic pressure.
C. Peak ventricular systolic pressure.
D. Peak ventricular diastolic pressure.
E. Peak systolic pulmonary artery pressure.

Question 5. Which of the following occurs at the arrow labeled 5?
A. Closure of the mitral valve; the first heart sound.
B. Closure of the aortic valve; the first heart sound.
C. Closure of the mitral valve; the second heart sound.
D. Closure of the aortic valve; the second heart sound.
E. None of the above is correct.

Question 6. The arrow labeled 6 represents:
A. Stroke volume.
B. Left ventricular end-systolic volume.
C. Left ventricular end-diastolic volume.
D. Right ventricular end-systolic volume.
E. Right ventricular end-systolic volume.

Question 7. The dashed line in the top graph represents:
A. Pressure in the aorta.
B. Pressure in the left atrium.
C. Pressure in the left ventricle.
D. Pressure in the right ventricle.
E. Pressure in the pulmonary artery.

Question 8. Which of the following occurs at the arrow labeled 7?
A. Closure of the aortic valve.
B. Opening of the mitral valve.
C. BOTH A and B are correct.
D. NEITHER A nor B is correct.

Question 9. Which three panels denote systole of the heart?
A. A, B, and C.
B. B, C, and D.
C. C, D, and E.
D. D, E, and F.
E. E, F, and G.

Question 10. Which of the following ECG waves represents ventricular repolarization?
A. P wave.
B. Q wave.
C. R wave.
D. S wave.
E. T wave.

Question 11. Which of the following statements about the heart is true?
A. Parasympathetic stimulation shortens the RR interval.
B. Most of coronary artery blood flow occurs during ventricular diastole.

C. A Valsalva maneuver increases venous return to the heart.

D. The function of the papillary muscles is to open the atrioventricular valves.

E. Sympathetic stimulation caused the heart rate to decrease.

Question 12. Which of the following would be seen with a delay in electrical conduction through the atrioventricular node?

A. ST segment depression.
B. Prolonged PR interval.
C. Inverted T wave.
D. ST segment elevation.
E. Prolonged QT interval.

Question 13. What effect does inspiration have on the heart?

A. It temporarily increases the heart rate.
B. It decreases venous return to the heart.
C. It causes the pulmonic valve to close just before the aortic valve.
D. It temporarily decreases the heart rate.
E. It lengthens the RR interval.

Question 14. Which ECG wave represents atrial depolarization?

A. P wave.
B. Q wave.
C. R wave.
D. S wave.
E. T wave.

ACKNOWLEDGMENTS

The authors would like to thank Penelope Al-Emam for handling the logistics of testing.

DISCLOSURES

General Electric Healthcare, through an educational partnership with the University of South Carolina School of Medicine, provides ultrasound systems and technical support for a student ultrasound curriculum.

AUTHOR CONTRIBUTIONS

Author contributions: F.E.B., L.B.W., and R.A.H. conception and design of research; F.E.B. and R.A.H. performed experiments; F.E.B. analyzed data; F.E.B. interpreted results of experiments; F.E.B. and L.B.W. prepared figures; F.E.B. drafted manuscript; F.E.B., L.B.W., and R.A.H. edited and revised manuscript; F.E.B., L.B.W., and R.A.H. approved final version of manuscript.

REFERENCES