Original Article

Use of Echocardiography as a Supplementary Tool in Teaching Cardiac Anatomy and Physiology to Medical Students

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Abstract

Background: **Ultrasonography has been increasingly used in teaching basic medicine. The simultaneous observation of the echocardiographic image and the electrocardiogram allows students to understand the physiological process of the heart and its function within the cardiovascular system.**

Objective: **Evaluate the acquisition and retention of knowledge among medical students during the study of cardiac anatomy and physiology through the use of echocardiography.**

Methods: **Thirty-four (34) students in the third semester took a pre-test (assessment 1) consisting of 20 multiple-choice questions, 15 of which were related to cardiac anatomy and physiology and 5 were "confusion-inducing questions." The test was designed by one of the authors, blind to the others. After the theoretical meeting, assessment 2 was carried out with the same questions. The following week, a practical echocardiography meeting was held, aimed at evaluating anatomy and physiology. A post-test (assessment 3) was carried out 30 days after the first meeting to assess knowledge retention. The variables were analyzed by the Kolmogorov-Smirnov, Student's T, and Wilcoxon tests, with a statistical significance level of $p < 0.05$.**

Results: **The average number of correct answers in assessment 1 was 6.37 ± 2.0 (42.4%), 9.8 ± 2.2 (65.3%) in the second assessment, and 10.3 ± 2.5 (68.6%) in assessment 3. There was a statistical difference between assessment 1 and the other assessments ($p = 0.01$).**

Conclusion: **Early introduction of echocardiography in the medical curriculum proves beneficial for imparting knowledge in cardiac physiology and anatomy, reinforcing theoretical understanding.**

Keywords: **Echocardiography; Education, Medical; Students, Medical; Anatomy; Cardiovascular Physiological Phenomena.**

Introduction

Medical education has changed drastically in recent decades. Technological advances have allowed ultrasound techniques to be increasingly used for teaching medicine, particularly for anatomy[1] and physiology[2] subjects. Studies have shown that students' perception of the use of ultrasound in teaching anatomy is positive[3,4] and it has already been demonstrated that the use of echocardiography was as effective as the dissection of cadavers in teaching cardiac anatomy.[5]

Echocardiography provides a visual representation of cardiac cycle events, facilitating the correlation between anatomical structures and their physiological functions. The simultaneous examination of the ultrasound image of the heart, the phonocardiogram, and the electrocardiogram enables students to grasp the physiological processes of the heart and its role within the cardiovascular system,[6] thereby enhancing diagnostic accuracy at the bedside.[7] Published articles indicate that instructing cardiac physiology through ultrasound methods aids students in learning and retaining knowledge about the events of the cardiac cycle.[4]

While computer programs exist to simulate cardiac cycle mechanisms,[8,9] echocardiography provides the added benefit of teaching an imaging method widely employed in diagnosing various cardiovascular pathologies, concurrently providing an understanding of physiological mechanisms and cardiac circulation.[4]

Since 2016, Indiana University in the United States has integrated echocardiography into its curriculum. It is introduced for students in the second-year pre-clinical cycle in order to assist in understanding the practice and teaching of cardiology.[10]

Similarly, our university incorporates echocardiography into the curriculum during the third semester, serving as a tool

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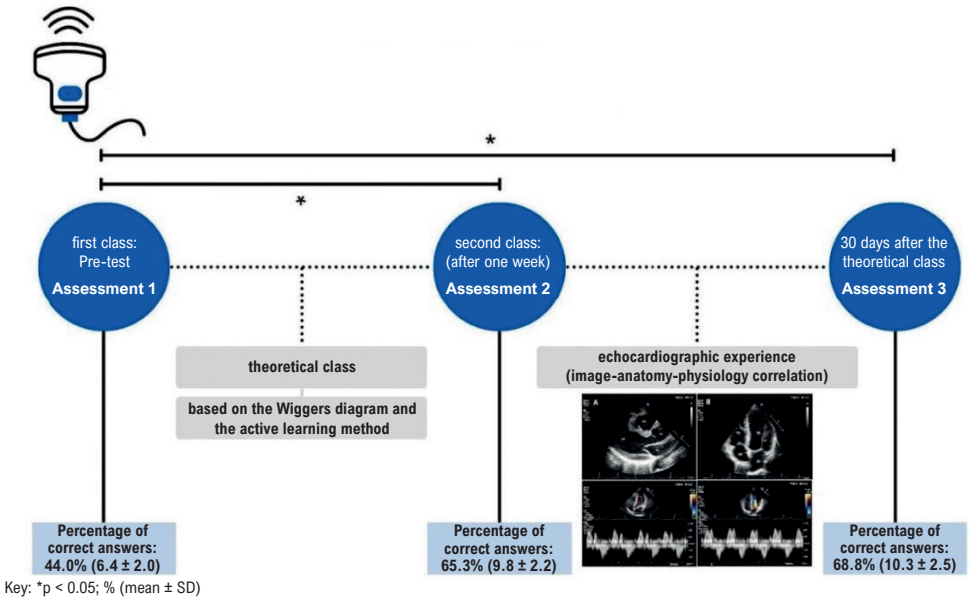
Central Illustration: Targeted use of Echocardiography as a supplementary tool in teaching cardiac anatomy and physiology to medical students



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to facilitate the teaching of cardiac physiology and enhance understanding of cardiac anatomy and the phases of the cardiac cycle. This study aims to assess the actual knowledge gain resulting from the integration of current medical teaching methods (active methodologies and Problem-Based Learning – PBL) with echocardiography practice.

Materials and methods

Study design

Prospective, single-arm study, with 34 students in the third semester of the Medical school program at UNIDAVI - *Centro Universitário para o Desenvolvimento do Alto Vale do Itajaí*, in Rio do Sul, state of Santa Catarina, Brazil.

Students were asked to answer a pre-test (assessment 1), with a duration of 20 minutes, consisting of 20 multiple-choice questions, 15 of them related to anatomy and physiology, and 5 "confusion-inducing questions" (see next topic). The assessment was prepared by the coordinating professor of the phase, maintaining blindness to the practice of echocardiography.

Subsequently, the group was divided into three groups for theoretical discussions involving the Wiggers Diagram (Figure 1).[11] Each sub-class had twenty (20) minutes to research atrial, ventricular, and arterial pressure curves, as well as ventricular volume, electrocardiogram, and phonocardiogram. For three hours, students delved into the theoretical part and were questioned by the professors, aligning with the course's active methodology. Following the theoretical discussion, a new assessment (assessment 2) was conducted, comprising the same questions as the pre-test and allowing the same time for resolution.

After a one-week interval, the students proceeded to the echocardiography laboratory. The practical meeting spanned 60 minutes and was conducted on the Affinity 70@ (Philips@) device. Initially, the formation of an ultrasonic image and the visualization of cardiac chambers in the transthoracic echocardiogram (ECHO) were discussed. Divided into four groups, they were prompted to correlate cardiac anatomy with the echocardiographic image in the parasternal longitudinal and apical four-chamber views (Figure 2).

Within cardiac physiology, the pressure and volume curves of the left atrium (LA) and left ventricle (LV) were discussed, utilizing pulsed Doppler of the LV inflow and outflow tract obtained in the apical 4th and 5th chamber views, respectively. Discussion was encouraged regarding diastole and ventricular filling times based on heart rate (Figure 3).

Finally, at the fifth time point and with a thirty (30)-day interval, the students undertook the last test (assessment 3) as a surprise test, featuring the same questions as the previous tests and providing the same time to answer.

Evaluation

The assessment was developed by the coordinating professor of the phase using the Google Forms® platform, administered as a surprise test on electronic devices with

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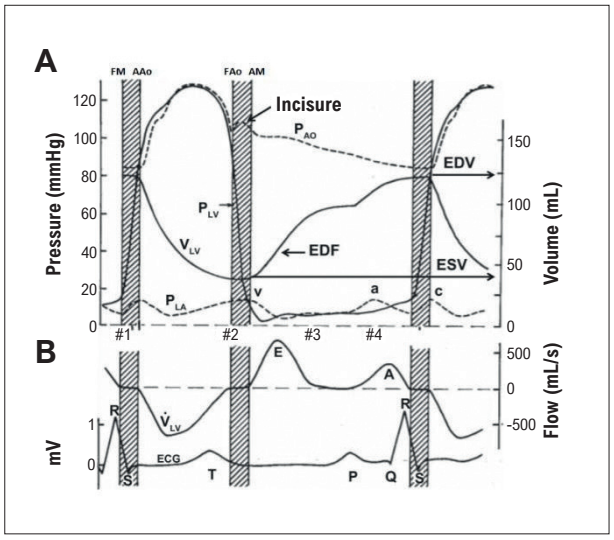

Figure 1 – *Wiggers Diagram. Key: A) Temporal correlation between ventricular pressure (VP), ventricular volume (VV), atrial pressure (AP) and aortic pressure (AoP). MVC: mitral valve closure; MVO: mitral valve opening; AVO: aortic valve opening; AVC: aortic valve closure; EDV: End diastolic volume; ESV: End systolic volume. #1 - B1 (mitral and tricuspid valves closure). #2 - B2 (aortic and pulmonary valves closure). #3 - B3 (third heart sound). #4 - B4 (fourth heart sound). B - Temporal correlation between blood flow during ventricular systolic ejection (VV) and diastolic filling waves (E and A waves of mitral inflow), in conjunction with the electrical impulses of atrial depolarization waves (P wave), ventricular depolarization (QRS complex), and ventricular repolarization (T wave) observed in the electrocardiogram (ECG). Adapted from Mitchell, 2014*[11]

restricted internet access. The questions were blinded to the practical instructor, and the content was covered in the echocardiography laboratory program. It was composed of twenty (20) multiple-choice questions (appendix 1), with fifteen (15) questions related to anatomy and physiology (the so-called "valid questions") and another five (5) "confusion-inducing questions" related to cardiology, but without addressing the topics discussed in theory and practice.

Confusion-inducing questions were introduced in the assessment to prolong the test, confuse students regarding the topic covered, and serve as control questions, since they do not explore the subject discussed in theory and practice. If assessment 1 solely focused on cardiac anatomy and physiology, the student would readily discern the designated topic and could engage in targeted study, artificially enhancing their performance in subsequent assessments. Consequently, these confusion-inducing questions showcase the student's capacity to enhance their knowledge and study without any didactic intervention.

Statistical analysis

The results of the three assessments were calculated in the SPSS® (Statistical Package for the Social Sciences) software version 26.0, using the Kolmogorov-Smirnov normality test.

Given the distribution of the sample, a normal distribution of these findings was found in the first and second assessments using the parametric Student's t test for paired samples. For the analysis of the third assessment, given the non-normal distribution, the non-parametric Wilcoxon t test was used.

The results were expressed as mean and standard deviation (SD), with the analysis considered statistically significant when p value < 0.05 ($\alpha < 0.05$).

Results

The sample was made up of 34 students from the third semester (basic cycle) of the Medical School program, 25 of whom were female and 9 male, with a mean age of 20.9 years (SD ± 3.5 years).

In the first assessment, the average number of correct answers to valid questions was 6.7 (SD ± 2.0), corresponding to 44.6%. The average number of correct answers to the confusion-inducing topics was 2.5. The question with the lowest percentage of correct answers was "During which phase of the cardiac cycle are the values of aortic diastolic (DBP) and systolic (SBP) pressure observed?" with only five correct answers (14.3%).

In the second assessment, the average number of correct answers to valid questions was 9.8 (SD ± 2.2), totaling 65.3%, and 2.6 correct answers to confusion-inducing questions. In this assessment, the question with the lowest number of correct answers was a confusion-inducing question: "The definition of sinus rhythm is based on the following findings, EXCEPT for," with only eight correct answers (21.1%).

In the last assessment, the average number of correct answers was 10.3 (SD ± 2.5), correlating with 68.8% of the total, and 2.45 correct answers to the confusion-inducing questions. Again, the question correlated with fewer correct answers was a confusion-inducing question: "During a heart attack, what electrocardiogram change determines the need for emergency coronary angiography (cardiac catheterization)?" with only seven correct answers (20.6%).

Using the parametric test, significant relevance was observed between assessments 1 and 2 ($p < 0.001$). There was also statistical significance using the non-parametric test to compare assessments 1 and 3 ($p < 0.001$). No difference between assessments 2 and 3 ($p = 0.14$) was observed (Chart 1), as well as in the rate of correct answers to confusion-inducing questions ($p > 0.3$).

In the comparative analysis of the correct answers to the valid questions by the students in the three assessments (Chart 2), a tendency for students to have a higher number of correct answers after the theoretical meeting was observed (assessment 2) and, mainly, after the practical meeting (assessment 3). Although there is no statistical significance in relation to assessments 2 and 3, the chart shows the student's knowledge retention tendency, given that the last assessment was applied thirty (30) days later.

Discussion

This study assessed the influence of incorporating echocardiography into the learning process of cardiology for students in the foundational stage of medical education. Our findings demonstrate that the early introduction

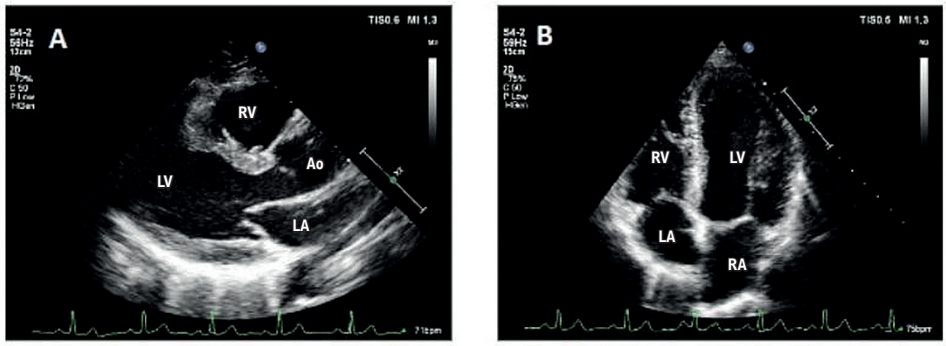

Figure 2 – Echocardiographic images in sections: A) Parasternal longitudinal; B) Apical four-chamber view. Key: LV: left ventricle; LA: left atrium; RV: right ventricle; RA: right atrium.

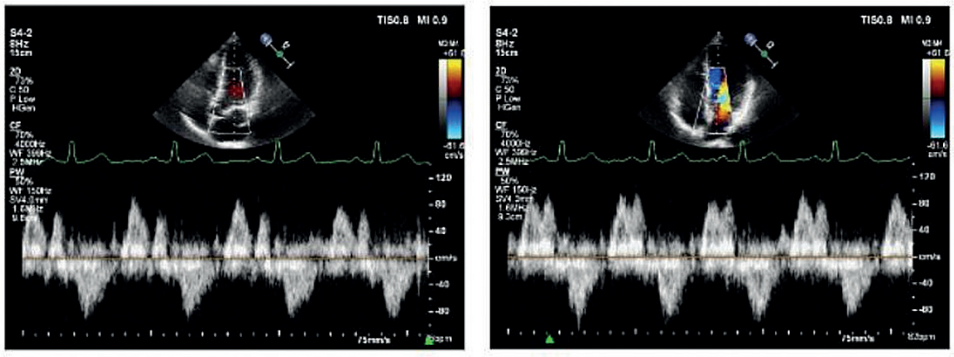

Figure 3 – Echocardiographic images in the Apical 4-chamber view of the inflow tract and outflow tract of the left ventricle with pulsed Doppler.

of echocardiography in medical education is not only feasible but also enhances the acquisition and retention of knowledge concerning cardiac anatomy and physiology among medical students.

Echocardiography bridges the gap between fundamental concepts and clinical applications, fostering student interest in the subject by emphasizing the need for a solid understanding of physiology for effective utilization of the method in clinical practice.[6] Teaching cardiac anatomy and physiology through ultrasound proves to be viable and beneficial for medical students, elevating their performance and fostering a greater enthusiasm for expanding their knowledge.[2] Educational activities that integrate echocardiography are well-received by students as they provide a tangible representation of the physiological processes within the heart.[12]

In certain studies, experimental anatomical models, echocardiography simulators, comparisons with anatomical practice, and cadaver dissection were employed to assess the knowledge gained by medical students. Torabi and colleagues, using a teaching software model, demonstrated the positive impact of introducing echocardiography to medical students during cardiology classes, both subjectively through student evaluations and objectively in practical tests.[10] Studies by Griksaitis, Sawdon, and Finn suggest that both anatomical dissection of cadavers and echocardiography are equally effective methods for teaching cardiac anatomy, with no significant superiority of one over the other.[5] This observation is supported by Canty *et al.*, who devised a three-hour practical session incorporating an ultrasound simulator as a supplementary tool for learning cardiac anatomy, and revealed that the knowledge acquired by students in this session was comparable to that obtained through the use of plastic models and cadaver dissection.[13]

Currently, some universities have used echocardiography to teach anatomy, clinical examination, and image acquisition to recognize some cardiac pathologies.[14] In our study, a notable knowledge gain was observed between the pre-theoretical assessment (assessment 1) and the post-echocardiography practice evaluation (assessment 3), with the percentage of correct answers rising from 44.6% to 68.6%. This result is comparatively lower than the study conducted by Bell *et al.*, where students' average correct score increased from 53.3% in the pre-test assessment to 81.7% in the post-test assessment.[4] In the work of Varadharaju and colleagues, 89.6% of students showed a better understanding of cardiac anatomy and physiology through real-time echocardiography.[15] Both studies performed the post-test assessment immediately after the practical class, and participants were voluntary.

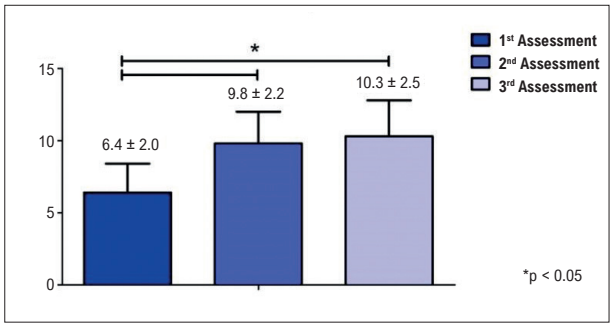

Chart 1 – *Average number of correct answers in assessments and standard deviation.*

Regarding knowledge retention, our study observed the maintenance and even enhancement of correct answers, correlating assessment 2, with 65.3% (after theory), and assessment 3, with 68.6% (30 days after practice). Numerous studies illustrating knowledge retention through the application of echocardiography are lacking in the literature. However, the research conducted by Jujo and colleagues revealed that, although there was a notable decline in the student's capability to capture Point of Care Ultrasound (POCUS) images after eight weeks, knowledge retention during this period remained consistent, with a slight reduction from 23.1 points to 19.6 points in comparison to the assessment conducted after the presentations, which was not statistically significant.[16]

Limitations and strengths of the study

Our work has certain limitations, such as the absence of a control group, preventing a direct comparison between the theory and practice of echocardiography. While it was initially suggested to create a control group when devising the study protocol, the lack of a standardized curriculum for teaching echocardiography in medical schools hindered this comparison. We encourage future comparative studies using our teaching methodology to pave the way for an appropriate curriculum.

Despite being the first study in Brazil to evaluate the effectiveness of an echocardiography laboratory for teaching cardiology, it was conducted in a single center using a methodology developed by the authors.

The investigation into knowledge retention occurred only four weeks after educational activities, due to the sequencing of the academic curriculum, which consists of Practical Skills III covering cardiology and pulmonology sessions. These sequential activities complement the study of cardiac anatomy and physiology and could interfere with the results of the assessments. Future studies should be carried out so that longer-term knowledge can be assessed.

The effective number of research participants aligns with sample calculations for educational interventions, recommending the inclusion of 25 or more participants in such studies.[17] Finally, the compulsory analysis of all students in the phase, without relying on volunteers, minimizes the risk of overestimation bias in the evaluation of medical education, as indicated by Callahan, Hojat, and Gonnella.[18]

Conclusion

Using transthoracic echocardiography as an instructional tool in cardiology education is viable within the medical curriculum, providing students in the foundational cycle with enhanced knowledge of cardiac anatomy and physiology.

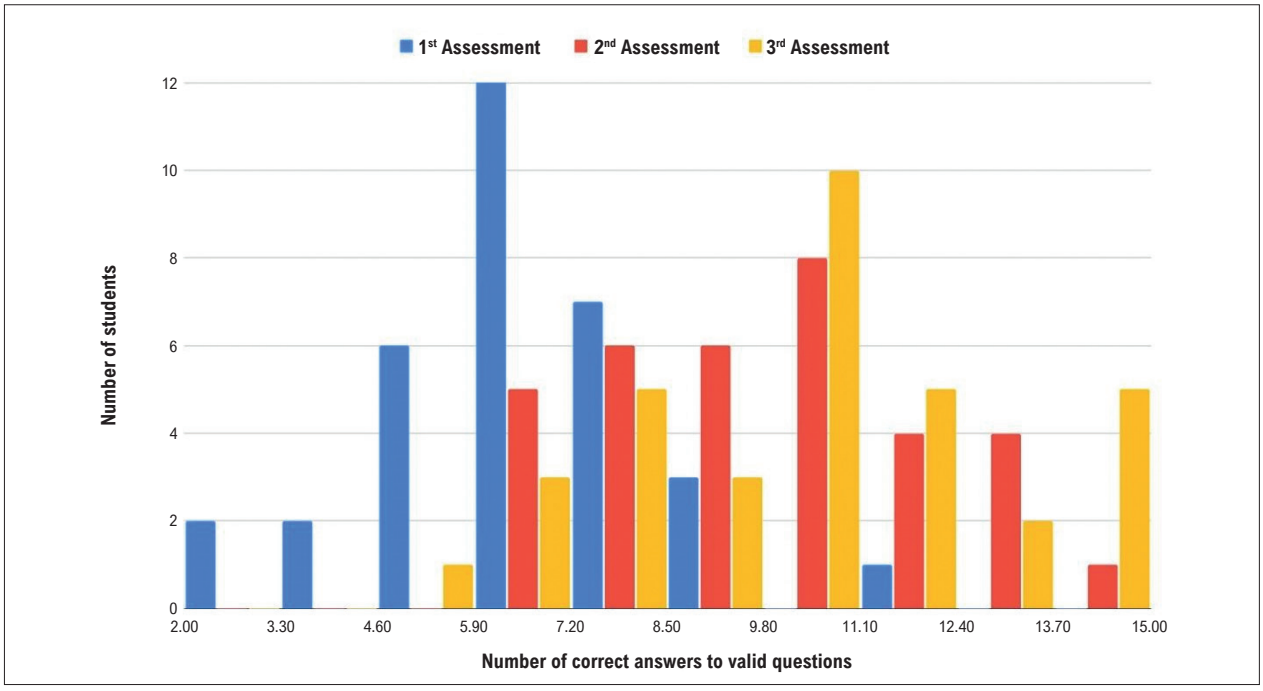

Chart 2 – *Comparative analysis of medical students' performance in evaluations.*

In addition to instructing on the acquisition of specific echocardiographic images for diagnosing particular cardiac pathologies, the incorporation of echocardiography into medical programs enhances students' capacity to assess the appropriateness of requested exams, along with their indications and proper interpretation.

Author Contributions

Conception and design of the research: Bacca COF, Toniazzo SRF, Matias LF, Kuhl ALN, Mees TN, Gambetta MV; acquisition of data: Bacca COF, Kuhl ALN, Mees TN, Gambetta MV; analysis and interpretation of the data: Bacca COF, Rocha FR; statistical analysis: Rocha FR; writing of the manuscript: Bacca COF, Toniazzo SRF, Rocha FR, Matias LF, Kuhl ALN, Mees TN, Ramos N, Gambetta MV; critical revision of the manuscript for intellectual content: Bacca COF, Toniazzo SRF, Ramos N, Gambetta MV.

Potential Conflict of Interest

No potential conflict of interest relevant to this article was reported.

Sources of Funding

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Study Association

This study is not associated with any thesis or dissertation work.

Ethics Approval and Consent to Participate

This article does not contain any studies with human participants or animals performed by any of the authors.

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