Biomedical Sciences
2023; 9(3): 73-77
http://www.sciencepublishinggroup.com/j/bs
doi: 10.11648/j.bs.20230903.14
ISSN: 2575-3924 (Print); ISSN: 2575-3932 (Online)

The Roles of Echocardiography in Teaching of Cardiovascular Physiology at Pre-Clinical Level of Undergraduate Medical Education

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To cite this article:

Suraj Adefabi Ogunyemi, Busayo Onafowoke Oguntola, Oluwadare Ogunlade. The Roles of Echocardiography in Teaching of Cardiovascular Physiology at Pre-Clinical Level of Undergraduate Medical Education. *Biomedical Sciences*. Vol. 9, No. 3, 2023, pp. 73-77.
doi: 10.11648/j.bs.20230903.14

Received: July 29, 2023; **Accepted**: August 25, 2023; **Published**: September 6, 2023

Abstract: Cardiovascular physiology is a foundational basic medical sciences course essential for safe clinical practice. Teaching and learning physiology are done traditionally using didactic lectures and practical sessions. However, the world is becoming tech-savvy and echocardiography is a critical player in the evaluation of cardiac physiology and pathology. This important tool is gradually gaining recognition as a useful tool for learning at the undergraduate level. This review aimed to provide evidence-based summaries that could guide and aid the incorporation of echocardiography into the teaching of cardiovascular structure and function among undergraduate medical students in Nigeria. This is a narrative review. Relevant literature was sought with the aid of academic databases and search engines using keywords. Appropriate information on the use of echocardiography for teaching cardiovascular to undergraduates within and outside Nigeria was synthesized and summarized taking cognizance of their relevance and applications. Evidence showed that in developed countries, integration of echocardiography into cardiovascular physiology education has been done and this was associated with a better learning experience and early formation of lifelong knowledge in the use of point-of-care ultrasound but data is sparse on this aspect of medical education in Nigeria. In conclusion, echocardiography is relevant, accessible, and applicable to teaching cardiovascular physiology at basic medical sciences faculty. Integration of echocardiography into the curriculum of the medical undergraduate in Nigeria is practicable.

Keywords: Echocardiography, Cardiac, Structure, Function, Teaching, Undergraduates

1. Introduction

Physiology is the study of the intricacies of life. It is one of the foundational courses offered by pre-clinical medical students in Colleges of Medicine. The aspect of physiology dealing with the heart and network of blood vessels is cardiovascular physiology. Conventionally, cardiac structures and functions, the fundamental component of cardiovascular physiology are taught through didactic lectures, practical demonstrations of physiological concepts, and the dissection of cadavers to understand anatomy. [1] These methods emphasize facts over the concept of teaching. [2] Adequate knowledge of physiology at the pre-clinical is required to be able to understand physiology as the basis for the exploration of the pathophysiological basis of diseases in clinical years. The understanding of physiology requires visuospatial skills. [3] A student's pre-existing visual-spatial ability is predictive of performance in medical gross anatomy. [3, 4]. To enhance the performance of students in cardiovascular physiology there may be a need to incorporate echocardiography to further enhance their visuospatial skills. [3-5] In recent times there has been an improvement in the ability to study the cardiac structure and functions at the bedside using non-invasive techniques such as echocardiography [6]. Studies have shown that echocardiography can help students learn from a visual point of view and better improve their understanding of the intricacies of the cardiac structure and function. [5] Also, it can help prepare students for patient management as echocardiography forms a common investigation modality for cardiac pathology. [7, 8]

2. Methodology

This is a narrative review. Relevant literature and documents on echocardiography evolution, the role of echocardiography in teaching cardiovascular physiology to undergraduates, and the challenges with the use of cardiac ultrasound technology to facilitate learning were explored. Academic databases were used as reliable repositories while the search engines provided dependable search guides using selected keywords. Appropriate information and reports on the use of echocardiography for teaching cardiovascular to undergraduates within and outside Nigeria were synthesized and summarized taking cognizance of their relevance and their applications to the subject.

3. Historical Perspectives

The history of ultrasonography dates back to 1880 when Pierre and Jacque Currie discovered piezoelectricity. [9] However, in 1953 Dr. Inge Edler and his team with Carl Hertz, a graduate of nuclear physics were able to record the first two-dimensional cardiac images. [9] In 1996, ultrasound education sessions were included as an adjunct to teaching basic sciences in preclinical medical school. [9] e g. Hannover Medical School in Germany, taught medical students anatomy using focused ultrasonography as an effective educational aid. [9] The technological advancement in ultrasonography has led to the production of portable, high-quality point-of-care ultrasound machines.

The role of ultrasonography has been assessed in teaching students about human cardiac physiology. Brunner et al reported in 1995 that echocardiography was included in the physiology curriculum of the student as it allows visualization of the cardiac cycle events and the correlation of anatomic structures with their physiological functions. [10] Also, on further evaluation echocardiography was reported as the most significant and interesting part of physiology. [10]

Nadjib et al in 2011 proposed the integration of echocardiography to train year two medical students after completion of their usual anatomy and physiology lectures and attending the scheduled written and practical examinations. [11] First, a brief theoretical introduction to the basics of ultrasound physics applied to medicine and a reminder of cardiac physiology and anatomy were performed by the teacher for 30 minutes using a standardized slideshow presentation. [11] Three hundred and forty-eight students were divided into 39 groups, of whom 330 (95%) effectively attended the course. The mean number of students per group was nine. A total number of 37 teachers, which included 21 intensivists and 16 cardiologists, participated voluntarily. The course was found useful by 98% of participants, and 85% and 74% of students considered that their understanding of anatomy and physiology was improved. Eighty-three percent had enhanced motivation to learn cardiac anatomy and physiology while 66% preferred ultrasound machine-aided learning. [11]

Similarly, Shetata et al in the College of Medicine of the University of Sharjah in the United Arab Emirates carried out a quasi-experimental pre-test/ post-test study design. The study assessed how the early integration of echocardiography into the medical curriculum can enhance the teaching and learning process of cardiovascular structure and function among year two preclinical students. The participants comprised 99 students who were introduced to both theoretical and practical sessions on the gross anatomy of the heart and the physiology of the cardiac cycle. Also, they were taught principles of echocardiography the year before without exposure to echocardiography. Echocardiography stimulated the interest of 88% of the students in anatomical and physiological basic science concepts. Furthermore, 92% of students reported that prior knowledge of anatomy and physiology is essential before having an integrated echocardiography session and 86% stated that this integrated mode of learning helped better consolidate the phases of the cardiac cycle. [1]

Also, Kondrashova et al. evaluated the understanding of electrocardiography, the ability to identify electrical and subsequent mechanical events during the cardiac cycle among medical students using live ultrasound imaging. [12] Results of the pre-and post-tests revealed significant improvement ($P < .05$) between the mean pre-test (56 %) and post-test scores (76 %). [12] The majority of students (99 %) completed the ultrasound assignment. Using ultrasound, resulted in a marked improvement in their understanding of cardiac electrical and valvular events and ventricular wall motion. [12] Also, they correlated electrical activity with cardiac mechanical events better, understood cardiac physiology, and developed skills that will indirectly enhance the quality of future patient care. [12]

In contrast to the self-reported increased measures of learning after ultrasound classes, Sean et al studied 132 students (65 with ultrasound, 67 without ultrasound scan) and found that small statistically significant gains in performance observed between the two groups were confounded by differences in pre-test performance between the groups. [13] Although this finding was attributed to the fact that some practical classes took place before the corresponding lectures on cardiac physiology, difficulty in enforcing that both classes completely got the same teaching experience and the inability to perform a post hoc analysis of exam performance between the ultrasound and non-ultrasound groups. [13]

Also, the improvement observed in the learning of cardiovascular physiology was independent of how the students were taught ultrasonography. A systematic review of 12 articles published between 2010 and 2014 focusing on the education of undergraduates using hand-held ultrasound scans revealed that most studies were conducted on cardiac ultrasound scans. Most participants were ultrasound naïve.

Also, hands-on, skills-teaching sessions, complemented by either didactic teaching (7 studies) or self-directed learning resources were used to teach the students the use of hand-held ultrasound scans. However, the review noted that students were majorly taught to identify pathologies rather than normal physiology. Also, available data are insufficient to guide: the appropriate use of ultrasound scans in medical education, the baseline competence required on ultrasound scans before students can be taught, limited availabilities of cardiologists and accredited cardiac ultra-sonographers to teach medical students, and uncertainty on the ability to retain skills over a long-term period. [14] Also, in a study by Asad et al the use of E-learning software to teach echocardiography to pre-clinical students was found to be appropriate. [7] It also enhanced their learning ability.

According to the International Consensus Conference recommendations on ultrasound education for undergraduate medical students, the important aspects are curricular integration across the basic and clinical sciences and a competency and trusted professional activity-based model. [15] Also, the curriculum should form the foundation of a life-long continuum of ultrasound education that prepares students for advanced training and patient care. [15] In addition, the curriculum should complement and support the medical school curriculum as a whole with an enhanced understanding of anatomy, physiology, pathophysiological processes, and clinical practice without displacing other important undergraduate learning. [15] The content of the curriculum should be appropriate for the medical student's level of training, evidence-based, expert opinion-based, and include ongoing collaborative research and development to ensure optimum educational value and patient care. [15]

Although there is rapid growth in the use of echocardiography in cardiovascular physiology, its use is limited by the need to train medical students for at least 8 weeks to gain the baseline competencies, time constraints, high cost of the ultrasound machine. [16] The training curriculum to achieve baseline proficiency in the use of echocardiography includes probe handling and connecting it to the anatomy of the heart, physics of ultrasonography, and obtaining and assessing information from a two-dimensional image in a three-dimensional organ. [8] Mullen et al in the United States of America evaluated the economics of ultrasound training using GE machines worth 37,000$ and additional materials such as 3 quarts of Aquasonic transmission gel (ParkerLabs) and towels worth 50$. [16] However, the study concluded that numerous expensive machines or instructors were not necessary to deliver introductory teaching on ultrasound scans. The study trained 28 students enrolled in the study over 4 weeks using a single ultrasound machine and an instructor teaching ultrasound for an average of 8 hours per week (faculty teaching time varied from 6 to 10 hours per week). [16]

4. The Echocardiography Modalities

Various types of echocardiography include transthoracic, transoesophageal, and intracardiac echocardiography. The echocardiographic modalities for the assessment of cardiac structure include Motion mode (M mode), 2-dimensional (2-D) mode, and 3-dimensional (3-D) mode while the echocardiographic modalities for the assessment of blood flow include pulse wave Doppler, continuous wave doppler, and colour flow doppler. Another imaging modality very useful for the assessment of myocardial wall velocity is tissue Doppler imaging. [17]

5. The Roles of Echocardiography in Teaching Cardiac Structure

Echocardiography is a useful tool for teaching the understanding of cardiac structure. Various aspect of the cardiac structure for non-invasive assessment includes the state of the pericardium including quantification of the volume of pericardial fluid, left ventricular internal diameter in diastole and systole, ventricular septum, interatrial septum, right ventricular diameter, aortic root diameter, left atrium diameter, cardiac valves morphology, aortic root diameter, and regional wall motion [18-19].

6. The Roles of Echocardiography in Teaching the Cardiac Cycle

The cardiac cycle consists of a series of events occurring within the heart from one heartbeat to the other. The cardiac cycle is divided into two main phases; ventricular diastole and ventricular systole. [20-21] Ventricular diastole is subdivided into isovolumic (isovolumetric) relaxation, rapid passive filling, slow filling, and rapid active filling (atrial contraction) whereas ventricular systole is divided into isovolumic (isovolumetric) contraction and ventricular ejection (Figure 1). Each of the phases and subphases of the cardiac cycle can be illustrated in real time using pulsed wave Doppler imaging (Figure 2).

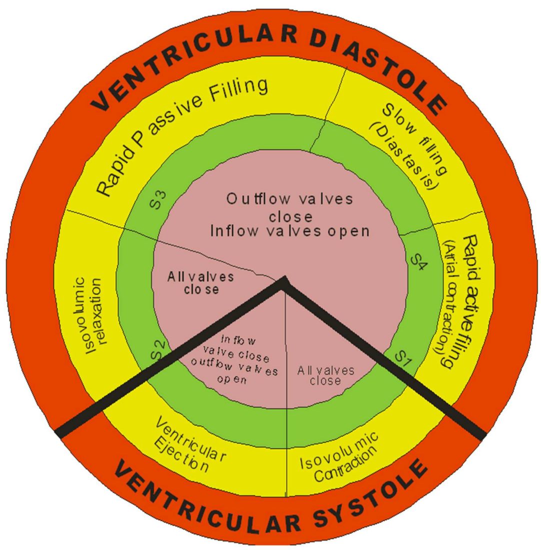

Figure 1. *Schematic Illustration of the Phases of Cardiac Cycle.*

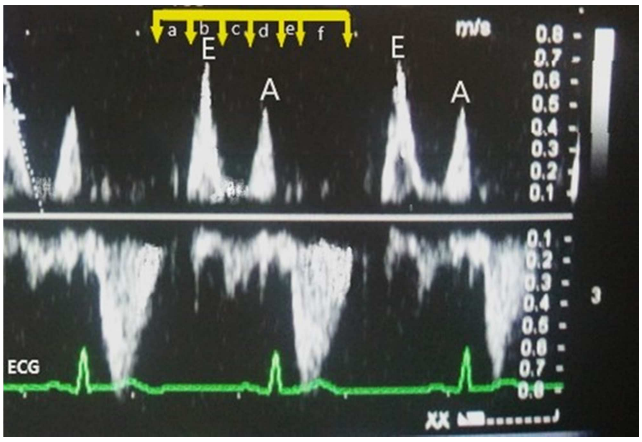

Figure 2. *Pulsed wave Doppler imaging (Apical 5-chamber view), illustrating the cardiac cycle.*

E = E wave, A = A wave
a= isovolumic relaxation, b = Rapid passive filling c = diastasis, d = atrial contraction,
e = isovolumic contraction, f = ventricular ejection

7. Phases of Cardiac Cycle

7.1. Isovolumic Relaxation

Isovolumic relaxation is a period occurring between the closure of the aortic valve (end of systolic ejection) and the opening of the mitral valve. During this period, all valves are closed, ventricular volume remains constant, ventricular walls relax and intraventricular pressures fall. When the intraventricular pressure falls below the atrial pressure, atrioventricular valves open to pave the way for the next phase of the cardiac cycle; rapid passive filling. The normal range for isovolumic relaxation time (IVRT) = 60-100ms. A prolonged IVRT is a marker of left ventricular diastolic dysfunction [20].

7.2. Rapid Passive Filling

The rapid passive filling is the period of initial ventricular filling. It begins with a rapid fall in intraventricular pressures below atrial pressures and atrioventricular valves (mitral and tricuspid) valves open. Due to differential pressure gradients between the atria and ventricles, blood flows rapidly from the atria to the ventricles resulting in 75-80% of ventricular filling. This phase produces E wave in pulse wave Doppler imaging of echocardiography (Figure 2) and it is also associated with the third heart sound (S3) among young people. The third heart sound can also be perceived when the heart is dilated. The rapid passive phase represents a complex interaction between ventricular suction (active relaxation) and visco-elastic properties of the myocardium (compliance). Towards the end of this phase, there is almost equalization of the pressures within the atria and ventricles resulting in the period called diastasis. [21]

7.3. Diastasis

Diastasis refers to a period of slow ventricular filling following rapid passive filling. It occurs when atria and ventricular pressures are almost equal. It precedes the period of rapid active filling. This phase is not always constant as it may be absent at a very rapid heart rate.

Each of these events in the cardiac cycle can be illustrated using pulsed wave Doppler imaging of echocardiogram (Figure 2) following interrogation of blood flow across the mitral and aortic valves. [20-21]

7.4. Rapid Active Filling (Atrial Contraction)

Rapid active filling refers to the period of atrial systole. Atrial contraction during this phase contributes 20-25% of the ventricular filling. It is represented by the A wave of pulsed wave imaging of echocardiogram (Figure 2) The fourth heart sound (S4) occurs during this phase. It ends at the closure of atrioventricular valves. The period depends on ventricular compliance, pericardial resistance, atrial force, and atrioventricular synchronicity. This phase precedes ventricular systole. [22-23]

7.5. Isovolumic Contraction

During the period of isovolumic contraction, all the valves are closed. As such, the ventricular volumes remain constant with elevation of the intraventricular pressures. When the intraventricular pressures exceed the pressures within the great vessels; the aorta and pulmonary trunk for the left and right ventricles respectively, the semilunar valves open, paving the way to the phase of ventricular ejection. [23] This phase is illustrated by the portion labeled e within the pulsed wave Doppler imaging (Figures 1&2).

7.6. Ventricular Ejection

During the period of ventricular ejection, the intraventricular pressures exceed the pressures in the aorta and pulmonary trunk for the left and right sides respectively. Semilunar (outflow tract) valves open. Blood is ejected into the aorta and pulmonary trunk on the left and right side respectively. Ventricular ejection is initially rapid, followed by slow ejection and then a fall in intraventricular pressure (*protodiastole*). [23] As the intraventricular pressures almost fall below the pressure in the great vessels, the semilunar valves close the end of the systole (Figures 1 &2).

8. Conclusion

In conclusion, echocardiography is relevant and applicable to teaching cardiovascular physiology at basic medical sciences faculty. Integration of echocardiography into the curriculum of the medical undergraduate in Nigeria is practicable.

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