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Ultrasound-based lectures on cardiovascular physiology and reflexes for medical students

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Paganini M, Rubini A. Ultrasound-based lectures on cardiovascular physiology and reflexes for medical students. *Adv Physiol Educ* 40: 243–247, 2016; doi:10.1152/advan.00010.2016.—Ultrasound has become a widely used diagnostic technique. While its role in patient evaluation is well known, its utility during preclinical courses such as anatomy and physiology is becoming increasingly recognized. The aim of the present study was to assess the feasibility/utility of integrating ultrasound-based sessions into conventional undergraduate medical school programs of physiology of the cardiovascular system and cardiovascular reflexes and to evaluate student perceptions of an ultrasound-based didactic session. Second-year medical students enrolled in the University of Padova attended a didactic session during which basic concepts regarding ultrasound instrumentation, image production, and spatial orientation were presented. Five anatomic sectors (the heart, aorta, neck vessels, inferior vena cava, and femoral veins) were then examined on a volunteer. Student perceptions of the images that were projected, the usefulness of the presentation, and the reproducibility of the experience were assessed at the end of the lecture with an anonymous questionnaire consisting of positive and negative items that were rated using a 5-point Likert scale and with two questions. One hundred eleven students attended the lecture; 99% of them found it very interesting, and none considered it boring or a waste of time. More than 96% thought it helped them to gain a better comprehension of the subject and would recommend it to a colleague. In conclusion, as ultrasound has been found to be a valuable resource for the teaching of physiology of the cardiovascular system and cardiovascular reflexes, efforts should be made to integrate ultrasound sessions into the traditional human physiology curriculum.

interdisciplinary medical education; human physiology; ultrasound; echocardiography; cardiovascular reflexes

ULTRASOUND IMAGING has become an important diagnostic technique in cardiovascular medicine, and physicians have been using it increasingly to assess patients' heart status (e.g., with echocardiography) and/or to analyze, in a noninvasive way, abnormalities of the main vessels (e.g., the supra-aortic great arteries, abdominal aorta, and venous vessels). Rapid advancements in ultrasound technology have led to the development of high-definition, increasingly smaller devices and have enabled the creation of so-called "bedside ultrasound," which is rapidly becoming an important tool in the clinical setting.

In educational terms, ultrasound is likewise becoming increasingly pivotal, and there is no doubt about the fact that future clinicians will need to be competent in ultrasound technologies and in interpreting ultrasound images in the clinical setting (4). Ultrasound teaching has begun to be included in some anatomy classes, but, for the most part, lessons are limited to slides or videos that are commented by the professor. Only a limited number of medical schools offer practical ultrasound laboratories and demonstrations providing medical students with an integrated ultrasound curriculum (1, 2, 7, 9).

Preclinical subjects, such as human anatomy and physiology, are traditionally based on frontal lectures with slides, cadaver dissections, and individual study (2). Several studies describing experiences of ultrasound-integrated anatomy classes, which have generally received positive feedback from medical school students, have, however, been reported in the literature (4, 8, 9, 11–14).

To date, only a few articles have reported on the use of ultrasound-based teaching of physiology: there is one experience about the respiratory system realized by our group (10), whereas there's a growing attention to the teaching potential of ultrasound in the cardiac field. A first experience about cardiac physiology was made by Brunner et al. (5) in 1995. Hammoudi et al. (6) described a module for second-year medical students who were shown cardiac cycle movements and were allowed to take the probe and carry out echocardiography on one another. Recently, Bell et al. (3) confirmed that cardiac ultrasound practical activities can help students with the acquisition and short-term retention of knowledge of nonelectrical components of the cardiac cycle. However, no attempt was made in the field of vascular physiology and cardiovascular reflexes.

The present study aimed to evaluate the outcome of an attempt to include a didactic ultrasound session within the context of a traditional cardiovascular system physiology and reflex course and to assess medical student perceptions toward this innovative approach.

METHODS

In June 2015, at the end of the academic year, second-year medical students attending the University of Padova (Padova, Italy) were proposed an ultrasound-based didactic session as part of their normal human cardiovascular physiology course. None of the students had previously been exposed to ultrasound-based classes as ultrasound techniques are traditionally presented after students have completed their preclinical classes, during their fourth academic year.

Students were informed about the session beforehand, and verbal consent was obtained. The study was approved by the local ethical committee.

Students were divided into two groups, and each group was assigned to one of two sessions scheduled at two different times on the same day. Sessions were held by an experienced medical sonographer (M. Paganini) and the professor of the human physiology course (A. Rubini). Male volunteer students, who gave informed consent, were scheduled to undergo an ultrasound examination in front of the class during the sessions, which were divided into two parts.

The first part, which lasted ~15 min, consisted of an introduction to specialized terms such as hyperechoic, hypoechoic, anechoic, acoustic bioimpedance, acoustic interface, and probe spatial orientation. Details concerning image formation and technical aspects of ultrasound physics were not discussed because these are covered

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Table 1. *The cardiac ultrasound images shown*

View	Anatomic Landmarks	Technique	Physiological Findings Shown
Apical four-chamber	Atria, ventricles, and great vessels	B mode	Cardiac cycle movements, myocardial walls and interventricular septum thickening, and pericardial sliding
		B mode	Valvular movements and tendinous chords during the cycle
		B mode	Ejection fraction: comparison between end-diastolic and end-systolic volumes in the left and right ventricles
		Color Doppler	Blood fluxes: diastole (atria → ventricles) and systole (ventricles → great vessels)
		ECG mode	Correlation between ECG and the cardiac cycle
Parasternal short axis	Ventricles, tendinous chords, and mitral valve	B mode	Myocardial walls: the differences between ventricle shapes and thicknesses
		B mode	Left ventricular myocardium concentric contraction
Parasternal long axis	Left atrium and ventricle, aortic and mitral valves, and ascending aorta	B mode	Relationship between the cardiac cycle and mitral/aortic valves movements
		Color Doppler	Blood fluxes

during the radiology course. Introductory comments were followed by an explanation focusing on the capacity of ultrasound to dynamically and in vivo show the anatomy, physiology, and pathology of patients. The advantages and disadvantages of ultrasound with respect to other imaging modalities and, in this case, with a standard chest radiograph were also discussed. Students were provided with the basic information necessary to follow the rest of the session.

In the second part, which lasted ~20 min, a male student volunteer underwent real-time ultrasound scanning that was performed and explained by the sonographer using a portable Xario 100 ultrasound device (Toshiba Medical System, Shimoishigami, Japan) with a convex probe (3.5 MHz), a linear probe (10 Mhz), and a sector probe (2.5 Mhz). The sonographic images were projected onto a large lecture screen easily seen by all of the students attending the session. The sonographer was assisted by the professor of physiology, who provided commentary and reiterated physiology concepts previously covered during lectures.

Five anatomic sectors of particular interest were shown: the heart, aorta, neck vessels, inferior vena cava, and femoral veins. To assist students in identifying normal anatomic structures, landmarks of every section were shown before the physiological movements and reflexes were projected.

Standard echocardiographic views were first provided using the sector probe; an explanation of cardiac physiology was presented while these were being projected. The cardiac cycle was shown, and notions about atrial and ventricular volumes, myocardial contraction phases, valvular movements, and heart sounds were discussed (Table 1). Simple calculations made by the sonographer were shown to obtain end-diastolic and end-systolic volumes of both ventricles: we asked students to estimate the ejection fraction by themselves and compare it with the professor's calculation. Furthermore, in ECG mode, particular attention was drawn to the P wave and the delay of QRS wave corresponding to ventricular contraction, also showed with the aid of slow motion.

Some physiological changes were provoked while showing the cardiac cycle (Table 2).

Three sections of the aorta were visualized using all ultrasound probes (Table 3). Doppler and color Doppler imaging techniques were used to examine blood fluxes. The descending aorta was not projected because of its complexity.

The neck vessels were shown using a linear probe concentrating on blood fluxes along the common carotid artery or internal jugular vein and their particular Doppler pattern, respectively, linked to the aortic flux and atrial pressures (Table 4).

Venous vessels such as the internal jugular vein, inferior vena cava, and femoral vein were visualized, and blood flow variations during the breathing cycle were illustrated (Table 5). With regard to the inferior vena cava, some difficulties were encountered using Doppler and color Doppler techniques due to the rapid movements of adjacent structures (e.g., the liver and diaphragm). It was possible to compress the femoral vein and to demonstrate pressure differences with respect to the femoral artery; venous valve opening and closures (preventing reverse blood flow) were visualized using longitudinal projections. The Doppler technique was not used for the femoral vein in view of the fact that clearly understandable reflex variations were lacking.

At the end of the demonstration, students were asked to complete an optional and anonymous questionnaire evaluating the lecture. The questionnaire was composed of two multiple-choice questions and 10 items (7 positive items and 3 negative items) that were to be rated using a 5-point Likert scale (where *1* = totally disagree, *2* = disagree, *3* = uncertain, *4* = agree, and *5* = totally agree). The internal consistency of the questionnaire was measured by Cronbach's α. Data were archived, and calculations were made using Microsoft Excel 2003. Data entry was double checked by a second researcher.

RESULTS

One hundred eleven students attended the lecture (63% of students in the class), and all students answered the questionnaire. The double-checked data were 100% concordant.

The means of the positive items shown in Table 6 were above 4 or, more precisely, were between 4.22 (*positive item 7*) and 4.59 (*positive items 4* and *5*). All students expressed total or partial agreement with *positive item 6* (100%). The percentage of students agreeing or totally agreeing with the remaining positive items were all above 90% except with reference to *positive item 7*, which also had the highest SD (0.71; Table 6).

With regard to the three negative items, the first ("Ultrasound visual interpretation was difficult") obtained the highest

Table 2. *The cardiac reflexes shown*

View	Technique	Stimulus	Reflex
Apical four-chamber and parasternal short axis	B mode	Quick deep inspiration*	Transient slight septal shift (right → left) and HR increase
		Valsalva maneuver†	Transient minimal HR reduction

*For the quick deep inspiration, the volunteer was asked to take a quick deep inspiration to maximal inspiratory capacity, resulting in a venous return increase with a slight transient septal shift (from the right ventricle to the left ventricle) and a modest increase in heart rate (HR). †For the Valsalva maneuver, the volunteer was then asked to perform a Valsalva maneuver causing a reduced venous return with a consequent transient decrease in cardiac output.

Table 3. *Sections of the aorta shown*

Probe	View	Anatomic Landmarks	Technique	Physiological Findings Shown
Sector	Parasternal long axis	Aortic root and ascending aorta (left ventricle and mitral and aortic valves)	Doppler	Dicrotic wave
			Color Doppler	Systolic blood flow and competent aortic valve closure
Linear	Suprasternal notch	Aortic arch (supraaortic vessels)	B mode	Aortic arch parietal movements synchronous with the heart cycle
			Doppler and color Doppler	Dicrotic wave and systolic blood flow
Convex	Abdominal: transversal and longitudinal	Abdominal aorta (vertebral body)	B mode	Shorter parietal movements with respect to the aortic arch
			Doppler and color Doppler	Dicrotic wave, lower amplitude, and systolic blood flow

mean and SD (2.03 and 1.02, respectively) and the lowest percentage (70.27%) of students voting "disagree" or "totally disagree." The two remaining negative items resulted as quite concordant with means tending to 1.1 and a percentage of disagreement of 100% (Table 6). With Cronbach's α at 0.72, the questionnaire showed good internal consistency.

When students were asked "What did you like most about using the ultrasound in the lecture?," the majority of students (46.85%) replied that they particularly enjoyed the in vivo display of physiology and 22.52% appreciated seeing anatomic associations. Some of the students were impressed by the simplicity of the ultrasound technique; others applauded its use within the context of traditional didactic strategies. When students were asked "How could ultrasound be helpful in your future medical school education?," many of the students (38.74%) were excited about its diagnostic potential, and others (25.23%) were convinced that it was a particularly important tool in some medical specialties (Table 6).

DISCUSSION

To our knowledge, this is the first attempt to introduce ultrasound into the traditional coursework of physiology to explain not only cardiac noneletrical concepts but also the physiology of arterial and venous vessels and the cardiovascular reflexes. Using this relatively novel modality, the physiology professor was able to illustrate with a greater impact on students the function of the cardiovascular system, physical relationships between its components, and basic reflexes.

The ultrasound session proved, according to the students' responses to the questionnaire, to be overall a positive experience. The rate of satisfaction was exceedingly high, as nearly all of the students (99%) found the lesson interesting, and not one of them considered it boring or a waste of time.

Just as focused ultrasound represents a useful approach to patient evaluation to answer specific questions in the clinical setting, it could likewise be used during physiology classes to answer students' questions by directly showing what happens in the human body and illustrating how to interpret the images being presented. Ultrasound is particularly efficacious in illustrating cardiovascular reflexes that occur within a few seconds of a stimulus because it captures them in a timely way. In fact, >95% of the students who were present at the session felt that they had a better understanding of anatomy and physiology and declared that their motivation to study was enhanced and that they would certainly recommend the experience to a classmate.

As the integrated lecture was held at the end of the course, students were prepared to apply the theoretical notions learned from lectures, laboratory sessions, and individual study to a real ultrasound experience; ~98% of students said they found the experience pertinent to the syllabus.

In our opinion, in the near future, ultrasound integrated lectures will be diffused in every university, allowing professors to explain directly during every lecture or to teach indepth some concepts at the end of the course: these methods for us are both valid and will be the standard education method. Professors will also need to reflect about the time dedicated to every notion, without using a great amount of time to explain everything that appears in the image but focusing on the concept and physiological process happening in the projection.

The basics of ultrasound images and spatial orientation outlined at the beginning of the session proved to be sufficient to permit the students to complete the session tranquilly. We did not investigate if the students were able to correctly interpret the ultrasound images that were presented as that was not one of the aims of the study. Ultrasound interpretation is an important part of the coursework of the radiology course offered to fourth-year students in Italian medical schools. Approximately 70% of the students claimed that the images were not difficult to interpret, 18% were somewhat less confident, and 12% admitted to encountering some difficulties. Some studies in the literature have supported integrating ultrasound relatively early along the medical training paradigm (2, 7, 9) to facilitate student studies. The findings of the present study agree with this view: obviously, our opinion is that professors should avoid images and projections difficult to understand (e.g., some abdominal viscera in the anatomy course) and show intuitive images.

Table 4. *Neck vessels shown*

View	Anatomic Landmarks	Technique	Vessel Findings Shown
Transversal or longitudinal lateral neck	IJV (CCA and EJV)	Doppler	CCA: dicrotic wave linked to the cardiac cycle IJV: waves linked to atrial pressure and the cardiac cycle

IJV, internal jugular vein; CCA, common carotid artery; EJV, external jugular vein.

Table 5. *Venous vessels shown*

Probe	View	Anatomic Landmarks*	Technique	Stimulus	Physiological Findings Shown
Linear	Transversal and longitudinal, lateral neck	IJV (CCA and EJV)	B mode	DI	IJV collapse
				VA	IJV caliber increase
			Doppler	DI	Difficult vision (collapse)
				VA	Flux reduction
			Color Doppler	DI	Difficult to illustrate (collapse)
				VA	Flux reduction
Convex	Right subcostal	Inferior vena cava (liver, diaphragm, and left atrium)	B mode and M mode	DI	IVC caliber reduction
				VA	IVC caliber constancy
			Doppler	DI	Not possible (artifacts)
				VA	Reduction in venous return
			Color Doppler	DI	Not possibile (artifacts)
				VA	Reduction in venous return
Linear	Transversal or longitudinal, inguinal region	Femoral vein (femoral artery)	B mode	///	Femoral vein compressibility
				DI	No significant effect
				VA	Venous valves closure
			Color Doppler	DI	Slight increase in blood flux
				VA	Significant blood reflux

DI, deep inspiration; VA, Valsalva maneuver.

The session described here was presented to a large group of students in the physiology classroom and not to small groups as it was not the aim of this study to teach ultrasound techniques. The purpose of the study was to evaluate, from the medical student's viewpoint, ultrasound as a teaching tool for potential use in the classroom. Methodological limitations include the small sample size assessed and the fact that the trial was held at a single medical school. The study evaluated the possibility of integrating ultrasound into traditional physiology courses by considering students' subjective opinions, but it did not investigate the long-term impact and retention linked to the session. Future studies could examine these aspects and other proposals to improve medical education.

In conclusion, recent advances in ultrasound have made this noninvasive imaging method pivotal in clinical settings and increasingly important in medical education. The present study demonstrates that ultrasound can be used beneficially in conjunction with traditional methods to teach cardiovascular physiology and to specifically illustrate the heart, vessels, and cardiovascular reflexes. Together with other studies in the literature, it supports exposing medical students to ultrasound early during preclinical courses, in accordance with the concept of ultrasound integrated

Table 6. *Items and open questions on the questionnaire and answers*

	Minimum	Maximum	Mean	SD	%Agreement	%Disagreement	%
Positive items							
The ultrasound integrated lecture:							
1. Was relevant to the physiology syllabus	3	5	4.54	0.54	98.20		
2. Was useful for a better understanding of anatomy	2	5	4.23	0.64	91.89		
3. Was useful for a better understanding of physiology	3	5	4.48	0.57	96.40		
4. Reinforced my interest in studying physiology	2	5	4.59	0.58	97.30		
5. Was interesting	1	5	4.59	0.59	99.10		
6. Was so useful I will recommend it to a colleague	4	5	4.54	0.50	100		
7. Could be useful for my future medical education	3	5	4.22	0.71	83.78		
Negative items							
The ultrasound integrated lecture was:							
1. Difficult to interpret the images	1	4	2.03	1.02		70.27	
2. Boring	1	2	1.17	0.38		100	
3. A waste of time	1	2	1.18	0.39		100	
What did you like best about the ultrasound session?							
Exposition of physiology							46.85
Exposition of anatomy							22.52
Simple to execute							12.61
Didactics							11.71
Reflexes							5.41
How could ultrasound be helpful in your future medical school education?							
Diagnostic use							38.74
Specialties (cardiology: 19, obstetrics/gynecology: 6, and internal medicine: 3)							33.34

%Agreement reflects the percentage of students who agreed or totally agreed; %Disagreement reflects the percentage of students who disagreed or completely disagreed.

meducation, which is a part of Free Open Access Meducation (FOAMed), resources to which nowadays health care professionals and students must access.

DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

AUTHOR CONTRIBUTIONS

Author contributions: M.P. conception and design of research; M.P. and A.R. performed experiments; M.P. analyzed data; M.P. interpreted results of experiments; M.P. drafted manuscript; M.P. edited and revised manuscript; M.P. and A.R. approved final version of manuscript.

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