18 Simulation in Non-Invasive Cardiology

James McKinney, Ross J. Scalese, and Rose Hatala

Introduction

The diagnostic abilities associated with the practice of noninvasive cardiology are, in many ways, a set of fundamental skills that most healthcare providers are expected to possess. Indeed, one of the first physical diagnostic skills medical students are exposed to and expected to acquire is minimal competence with cardiac auscultation. Recently many healthcare educators believe that the ability to visualize the heart and determine its functional status may supplant the ability to listen to heart sounds. Some have gone so far to call the echo probe the "new stethoscope." In light of this development, basic echocardiography will likely find its way into early medical school curriculums and physical diagnosis courses. In any case the noninvasive cardiac exam has evolved over time, but fundamental physical diagnostic skills remain a core competency for the cardiologist as well as any provider. Although these skills can and will be taught on actual patients with limited risk or harm, the ability to predictably expose all students to a given set of normal and pathologic sounds and images makes simulation a powerful tool in the educator's armamentarium. This chapter focuses on non-invasive cardiology-based simulation for medical education. We begin with a focus on the simulation of the cardiac physical examination and conclude the chapter with an overview of echocardiography simulation.

J. McKinney, MD, MSC (✉)
Department of Cardiology, University of British Columbia, 301-2100 3rd. Ave. W., Vancouver U6R 1 LI, BC, Canada
e-mail: mckinney.jimmy@gmail.com

R.J. Scalese, MD, FACP
Division of Research and Technology, Gordon Center for Research in Medical Education, University of Miami Miller School of Medicine, PO Box 016960 (D-41), Miami, FL 33101, USA
e-mail: rscalese@med.miami.edu

R. Hatala, MD, MSc
Department of Medicine, University of British Columbia, Vancouver, BC, Canada

Department of Medicine, St. Paul's Hospital, Suite 5907, Burrard Bldg., 1081 Burrard St., Vancouver, BC V6Z 1Y6, Canada
e-mail: rhatala@mac.com

The Importance of Cardiac Physical Examination Skills

Proficiency in cardiac auscultation remains an important skill in clinical medicine [1]. Cardiac examination can accurately detect most structural cardiac conditions when performed correctly [2]. It is a noninvasive tool that can directly diagnose and assess severity of disease and guide further evaluation and therapeutic management [1]. Despite its role as an invaluable diagnostic tool, proficiency in this skill remains poor [2]. This was highlighted by Mangione and Nieman [3] who found that only 20% of audio-recorded auscultatory findings were recognized correctly by family practice residents, internal medicine residents, and medical students. Furthermore, there is minimal improvement with increasing levels of clinical experience, implying that trainees are not developing these skills as they progress through residency [2, 4].

Poor cardiac examination skills among trainees have been attributed to a number of factors: less formal teaching dedicated to the cardiac physical examination, less opportunity for trainees to encounter patients with cardiac pathology, and less time spent in direct patient contact yielding fewer opportunities to practice physical examination skills and receive feedback on performance [5]. This phenomena has also lead to a shortage of clinically oriented instructors proficient in cardiac examination, as even practicing physicians lack self-confidence in the physical examination [2]. The increasing reliance on imaging technology at the expense of physical examination may also play a role.

There is thus a clear need for better methods by which to teach cardiac auscultation and diagnostic skills for all levels of learners. The ideal learning environment would include the opportunity for students to examine real cardiac patients

A.I. Levine et al. (eds.), *The Comprehensive Textbook of Healthcare Simulation*,
DOI 10.1007/978-1-4614-5993-4_18, © Springer Science+Business Media New York 2013

with an opportunity to review each patient with an expert on repeated occasions [6]. Due to the constraints outlined previously, this is not possible in most clinical or educational environments. Thus, students are expected to learn cardiac examination skills from random, unstructured patient encounters during their clinical clerkship, an approach which is, given the evidence, inadequate [7].

Simulation provides an opportunity to address these deficiencies by recreating cardiac abnormalities for the express purposes of exposure, teaching, and repetition (i.e., deliberate practice) [6]. A simulator can provide standardized physical findings for a wide variety of conditions with options for titrating the severity and progression of the disease [5, 8]. Simulation also provides a safe, supportive environment where education and assessment can take place [9]. Furthermore, it allows learners at all levels to practice and develop skills with the knowledge that mistakes carry no penalties or harm to patients or learners [10].

Current Use of Cardiology Simulation in Medical Education

Medical educators have recognized that simulation can play a key role in the development and maintenance of proficiency in the cardiac physical examination. In a 2011 survey by the Association of American Medical Colleges, medical students at over 80% of responding institutions were exposed to some form of simulation (from standardized patients to technology-enhanced simulators) during medical school. Residents also had a high use of simulation early in their residency programs. Examining the content of the simulation-based teaching, approximately 30% of programs taught topics relevant to cardiology which would include physical examination [11]. Interestingly, this is quite similar to the prevalence of dedicated formal cardiac physical examination instruction reported by Mangione et al. in the 1990s [4].

The ultimate goal for simulation-based cardiac physical examination teaching is to facilitate learning of cardiac physical examination skills and diagnostic accuracy and for this to translate into improved skills and accuracy in clinical practice. In the following sections in this chapter, we examine the simulators available for cardiac physical examination teaching and explore effective methods for employing this technology.

Types of Simulators

A wide range of simulators have been developed to aid in the development of cardiac auscultation skills and knowledge. Examples include standardized patients, audio recordings, multimedia CD-ROMs, computer-assisted instruction, virtual patient encounters, electronic heart sound simulators, and mannequins. Each of these modalities has proposed theoretical and documented benefits and limitations as will be reviewed below.

Table 18.1 Exclusively audio simulators

Benefits	
	Portable and easily accessible. Learners can work through diagnoses at their own pace
	Opportunity for self-practice and repetitive practice
	Not constrained by patient or instructor availability
	Multiple examples of a single diagnosis can be presented quickly and economically
Limitations	
	Unable to correlate sounds with tactile or visual patient cues. Lack of interaction with physical "patient" (real or simulation)
	In the absence of instructor, lack of interaction and feedback regarding auscultatory abnormalities

Audio Simulations (Table 18.1)

Audio simulations, which typically consist of CD-ROMs but can include other sound file formats, present recordings of real or simulated patient heart sounds. The benefit of this approach is that the recorded audio sounds are free of contaminating background noise commonly found at the bedside, so it may be easier for the learners to hear the sounds [3]. This is unlike the difficulties encountered when listening to a patient's heart in a noisy setting, such as the emergency department, where a conventional acoustic stethoscope is unable to filter the additional environmental noise making auscultation more challenging. For novice learners, the absence of extra visual and tactile stimuli may simplify the task at hand and improve their auscultatory accuracy. Supporting this argument, Vukanovic-Criley et al. noted that learners and clinicians at all levels of experience would close or avert their eyes when auscultating a virtual patient that processed a combination of sights and sounds. This was done instinctively, despite the fact that doing so would mean the clinician would actively choose to ignore visual reference that could have assisted them the timing of sounds and murmurs [2].

The efficacy of the audio simulations has been demonstrated in at least two studies [12, 13]. Horiszny demonstrated that repetitive auscultation of heart sounds and murmurs with interactive discussion about pathophysiology with an instructor improved the cardiac auscultatory proficiency of family medicine residents [13]. Auscultatory diagnostic accuracy improved from 36 to 62% after three 45-min sessions, as tested using the simulated sounds. A similar study confirmed the utility of the audio recordings for medical students after a 2½-h session with an instructor [12]. These studies demonstrate the effectiveness of repetitious listening to heart sounds when enhanced by the

Table 18.2 Multimedia simulators

Benefits	
	Able to present interactive cases with additional supportive history, laboratory tests, and explanations of pathophysiology
	Incorporation of visual stimuli, such as ECG tracings, pulse waveforms, videos of carotid pulses, JVP, and precordium, to help correctly locate and identify heart sounds and murmurs
	Opportunity for self-practice and repetitive practice
	Not constrained by patient or instructor availability
Limitations	
	In the absence of instructor, limited feedback from computer (absence of feedback with non-CAI multimedia formats)
	Lack of interaction with physical "patient" (real or simulation)
	More expensive and less accessible than exclusively audio simulations

presence of an instructor providing feedback and guiding group discussion.

Another study powerfully demonstrated the importance of repetitive listening to heart sounds and murmurs [14]. Third-year medical students either listened to 500 repetitions of 6 simulated heart sounds and murmurs, recorded on a 1-h CD, or were not exposed to any recorded sounds. Those students who engaged in repetitive practice had significantly higher diagnostic accuracy on both simulated and real patient heart sounds.

These studies support the efficacy of pure auscultatory simulations in improving diagnostic accuracy, at least as tested on auscultatory simulations. These types of simulators are well suited to novice learners and require only a few hours of repetitive practice to demonstrate significant learning gains.

Multimedia Simulations (Table 18.2)

CD-ROM

It has been hypothesized that the lack of information regarding location, intensity, and radiation of the murmur may limit the utility of the exclusively audio simulations [14]. Critics of these simulators suggest that listening to heart sounds and murmurs in isolation without visual and tactile stimuli is not reflective of auscultation at the bedside [3]. Multimedia cardiac simulation typically involves audio recordings of heart sounds with visual stimuli in the form of graphics, ECG tracings, phonocardiograms, and video recordings of the jugular venous pulsation (JVP), carotid arteries, and precordium. Additionally, some of these simulations have supplementary history, imaging (e.g., CXR, echocardiogram), and teaching points. The primary characteristic of multimedia cardiac simulations is the ability to identify systole and diastole through the visual modality, allowing the user to properly time auscultatory findings within the cardiac cycle.

Multimedia CD-ROMs have been shown to improve cardiac auscultation knowledge and skill [3, 6, 15, 16]. The study designs include a single-group pre-post study [16], cohort studies comparing multimedia to classroom teaching [15, 16], and multimedia plus traditional clerkship to clerkship alone [6, 15]. For example, Stern et al. [6] found that students who were exposed to CD-ROM cases demonstrated improved diagnostic accuracy when tested on simulated sounds compared to students who only experienced the traditional clerkship instruction. Furthermore, the subset of students who had the full intervention (reviewing in-depth CD-ROM cases and 20 mini-cases) had a preservation of auscultatory skill when retested 9 months later.

In the study by Stern et al., and in another study by Finley et al. [6, 15], students used the multimedia simulations either on their own or in the presence of an instructor. Both studies demonstrated similar diagnostic accuracy on simulated heart sounds between both instructor present and instructor absent groups. These studies suggest that students can use these simulations independently and demonstrate significant gains in skills. However, from the students' perspective, they felt that a combination of both classroom and computer learning would be preferable to either modality alone [15].

Computer-Assisted Instruction

For our purposes, computer-assisted instruction (CAI) is defined as a multimedia simulation program that uses computer programs or Web-based learning as the central means of information delivery *but* is also interactive. Within cardiology, considerable interest in CAI has led to the development of CAI modalities for teaching cardiac physiology and cardiac physical examination skills. Conceptually complex, visually intense, and detail-oriented tasks such as understanding the pathophysiology behind a murmur are well suited to CAI [15]. An interactive computer screen can show animations of anatomy, ECG tracings, pressure-volume curves, and echo images, in addition to supplementary text or audio instruction to help the learner acquire the necessary background knowledge. This can then be coupled with heart sound recordings and videos of physical examination to serve as a comprehensive presentation of a particular cardiac condition. Similar to the multimedia CD-ROMs, CAI allows the student to engage in self-directed learning in a nonthreatening environment [17]. Both multimedia modalities generally do not require immediate direct supervision from the instructor, thus reducing the geographical and time constraints on both students and instructors [17].

Perhaps the best studied example of a cardiology-specific CAI is the UMedic system (University of Miami medical education development system for instruction using computers) [18, 19]. Developed to be used in conjunction with Harvey® The Cardiopulmonary Patient Simulator, UMedic is a multimedia program that presents an extensive cardiovascular curriculum, incorporating cardiac auscultation and

Fig. 18.1 Harvey® The Cardiopulmonary patient simulator (Photo courtesy of Laerdal)

cardiovascular imaging in its presentation [20] (Fig. 18.1). It has been shown to improve diagnostic accuracy on simulated cardiac findings, for clerkship students, compared to a traditional clerkship rotation [19].

Sverdrup et al. [21] addressed whether traditional bedside teaching versus training with CAI would lead to differences in diagnostic accuracy with real patients. Two groups of third-year medical students received a 2-h instructional session focused on cardiac examination and physiology. One group received an additional 2-h traditional bedside teaching session, while the other group went through a series of cases with the multimedia simulation. Both groups had equal diagnostic accuracy when tested with real patients.

Virtual Patient Encounters

Virtual patient encounters (VPE) are defined as "a specific type of computer program that simulates real-life clinical scenarios; allowing learners to obtain a history, conduct/view a physical exam, assess diagnostic tests and make diagnostic and therapeutic decisions" [21, 22].

These interactive multimedia teaching programs use real or standardized patients filmed at the bedside with supplemental animations, demonstrations of anatomy, ECG tracings, echocardiogram images, and text or audio instruction. In addition to the ancillary information, actual recorded heart sounds and actual video recordings of a live patient are presented. The VPEs permit the learner to move the virtual stethoscope over the virtual patient's precordium while observing pulses, respiration, and/or postural maneuvers [7].

Virtual patient encounters can improve the cardiac examination competency of medical students [7]. In one study, 24 medical students received eight 90-min sessions with a VPE in addition to their baseline core curriculum and were compared to 52 students receiving no additional instruction. The VPE group improved their diagnostic accuracy when tested on the VPE compared to the control group. Moreover, a subset of students in the intervention group was tested 14 months later and had a sustained increase in accuracy compared to the control group. VPEs have also been used to assess the knowledge and auscultation skills of medical students, residents, fellows, and clinicians [2].

Despite the appeal of multimedia simulations, whether CD-ROM, CAI, or VPE, there still exists a need for more well-designed studies examining how best to use these simulation modalities. The majority of studies employ nonrandomized designs, add multimedia simulators to instruction received by both groups as opposed to comparing two interventions that require equal time, and test learners using the multimedia simulator as opposed to real patients. Without stronger research designs, and particularly without demonstrating the translation of skills from simulation to real patients, the benefits of multimedia simulations remain under-explored.

Table 18.3 Standardized patients

Benefits
Real person with which to interact
Ability to learn the techniques and cardiac findings of the normal cardiac physical examination
Patient and/or instructor present to provide feedback on performance
Potential for "hybrid" simulations, combining the normal physical examination of the patient with any of the simulation modalities presenting the cardiac abnormalities
Limitations
Typical standardized patient does not have cardiac abnormalities, thus unable to present abnormal physical findings
Inefficient, as only a few students can examine the patient at any one time
Not conducive to repetitive practice or available for independent practice
Cost and time intensive to recruit and train appropriate standardized patients

Standardized Patients (Table 18.3)

A standardized patient (SP) (see Chap. 13) is an actor or patient who has received training to present his or her history in a standardized, reliable manner and who sometimes mimics physical signs [10]. The use of SPs for teaching the basics of cardiac physical examination is widespread in North American undergraduate medical education, as is their use in assessment [11]. SPs may be helpful for teaching normal physical exam findings and instructing learners in physical exam technique. However, the SP's normal physical exam poses a problem when assessing learners' ability to recognize abnormal clinical signs and to apply and integrate knowledge [23]. There is a low correlation between clinicians' physical examination technique and their ability to diagnose cardiac abnormalities [24].

Fig. 18.2 Lecat's Ventriloscope (Picture courtesy of Limbs & Things ©2012 www.limbsandthings.com)

Table 18.4 Cardiopulmonary simulators

Benefits	
	Simulate physical patient, with palpable pulses, JVP waveforms, precordial movements, and simulated heart sounds. Facilitates comprehensive physical examination as would be performed on a real patient
	Allows for repetitive practice and can provide opportunity for self-practice
	Typically, instructor present to provide feedback on performance
	Multiple learners can listen to and examine the simulator at the same time, without the issues of real patient fatigue
Limitations	
	More expensive and less accessible than other simulator modalities. A single institution may have only one cardiopulmonary simulator, thus limiting learner access to the simulator
	Typically only have one or two examples of each diagnosis
	Although self-study modes are available, typical presence of instructor is faculty intensive

Lecat's Ventriloscope, manufactured by Limbs & Things, is a modified stethoscope that allows prerecorded sounds (activated wirelessly) to be integrated with a standardized patient [23]. It is designed to overcome some of the limitations of the SP with normal physical findings. The Ventriloscope allows for projection of abnormal auscultatory signs onto a healthy person, requiring students to recognize and interpret such signs within the wider context of a clinical encounter [25]. The learner also benefits by completing the cardiac examination on a live person. Additionally, the same SP can have a number of cardiac conditions that can be interchanged with ease (Fig. 18.2).

Limitations of early Ventriloscope models included lack of synchronization of cardiac auscultatory findings with the SP's pulse and lack of respiratory variation of the heart sounds. Technology is being developed to track the pulse (by having the SP wear a heart rate monitor) and trigger the recorded sounds simultaneously. A foreseeable limitation to the Ventriloscope is that it simulates auscultatory abnormalities, but cannot simulate associated physical examination findings, such as JVP or pulse abnormalities. The Ventriloscope is a relatively new technology, and comparative effectiveness studies are not presently available.

For teaching cardiovascular physical examination, perhaps the ideal use of the SP is to combine the teaching of the normal cardiac examination with recognition of auscultatory abnormalities using any one of the simulation modalities. Although such "hybrid" or integrated simulations are being used in other domains, especially invasive procedural skills training [20, 23, 26–29], and despite the prevalent use of SPs in the medical education system, there is little research examining how best to use them for cardiac physical examination teaching.

Cardiopulmonary Simulators (CPS) (Table 18.4)

Cardiopulmonary simulators (CPS) are mannequin-based simulators that have palpable pulses, JVP waveforms, precordial movements, and simulated heart sounds. Conceptually, CPS have great potential as tools to enhance the education of learners' cardiac examination skills. By more closely mimicking a real patient, CPS allow a full cardiac examination, integrating all sensory information. Cardiopulmonary simulators can replicate abnormal pathology and can be reviewed at the instructor's and learner's convenience, thus alleviating the constraints of patient and pathology availability. Unlike real patients who may tire from being examined by multiple trainees, multiple learners can listen to and examine the simulator at the same time, thus increasing the efficiency of teaching.

Almost all of the research into the effectiveness of CPS as a teaching modality has been undertaken using Harvey®. Across multiple studies, it has been demonstrated that instruction with Harvey®, either in isolation or in conjunction with the UMedic multimedia system, can improve novice and resident learners' diagnostic accuracy on Harvey® and on real patients [20, 23, 26–29]. Typically, these are single-group studies, but one was a cohort design comparing a fourth-year medical student cardiology elective focused on Harvey® examination in addition to real patients to a traditional elective focused on real patients. There was a small but statistically significant superiority in diagnostic accuracy with real patients for the Harvey®-trained students [28].

There has only been one study that compared CPS to another simulation modality for teaching cardiac physical examination skills [30]. This study suggested that instruction with Harvey® was no more effective than instruction using CD-ROMs [30], but limitations of the study design including no pretest to establish equivalence of the two groups at baseline and difficulty establishing equivalence of the post-tests done with real patients limit interpretation of the results. In one study using only CPS, medical students demonstrated a transfer of skills from CPS to real patients for a cardiac murmur presented on the CPS but a lack of transfer from simulated murmurs that were different from the real patient's diagnosis [31]. Thus, the comparative benefit of CPS over other simulation modalities remains largely unexplored.

Overall, it appears as though most forms of cardiac physical examination simulation can provide effective instruction in cardiac physical examination skills. There is a perceived relationship between greater physical fidelity of a simulator and better learning outcomes [30]. Kneebone has suggested that developers and educators have primarily focused on creating lifelike simulators and have forgotten to ask whether low-cost, low-fidelity simulators are able to produce similar results in teaching and learning [32]. Likely of more importance than the specific simulator is how the simulator is incorporated into any teaching session. As shown by Barrett et al., repetitively listening to cardiac abnormalities can significantly improve diagnostic accuracy [14]. The exclusively auditory and multimedia simulations are able to present many examples of the same diagnosis conveniently and economically, whereas the CPS may only have one or two representations of a particular diagnosis [30].

As outlined in a review of effective instructional design features for simulation-based medical education, the instructional session should incorporate the principles of feedback to learners on their performance, integration of the teaching session into the curriculum and deliberate practice and mastery learning [32]. Mastery learning describes an instructional approach wherein learners must "pass" a learning unit before proceeding on to the next unit. In cardiac physical examination, this was implemented by Butter et al. who taught medical students using mastery learning principles with a multimedia tutorial and CPS [29]. Using this approach, trained third-year medical students had better diagnostic accuracy examining real patients compared to fourth-year students who did not experience the course.

There is little doubt that in this era of reduced in-hospital patient volumes, larger medical school class sizes, and reduced faculty availability for teaching, simulation-based education for cardiac physical examination is a necessity. Simulation affords an opportunity for learners to work independently and at their own pace, to teach large numbers of learners multiple cardiac abnormalities, and to reserve teaching with real patients to learners with a basic skill set. Not only is patient contact opportunistic, it may not be the most efficacious method for students to learn an essential competency.

The field of simulation-based education for cardiac physical examination would benefit from more rigorous educational studies. Our understanding of how to use these potentially expensive resources would be strengthened through randomized, controlled study designs, examining different instructional approaches, comparing different simulation modalities directly, and assessing outcomes using real patients.

Echocardiography

Echocardiography is one of the most important diagnostic tools in cardiology and has an ever-growing role in perioperative anesthesia and in critical care. Echocardiography provides detailed information about cardiac structure and function. Clinically important information can be provided in real time to assist clinical decision making [34]. The two forms of echocardiography commonly used are transthoracic echocardiography (TTE) and transesophageal echocardiography (TEE). Proper interpretation of either modality requires extensive knowledge of cardiac anatomy, cardiac physiology, and visualization of image planes. Although both TTE and TEE employ the same echocardiographic principles to assess cardiac structure and function, each modality has its strengths and limitations.

Transthoracic Echocardiography (TTE)

Transthoracic echocardiography involves placing the ultrasound probe on the surface of the chest in various locations to obtain different image planes of the heart. Transthoracic echocardiography is noninvasive and has the ability to dynamically monitor cardiac function and accurately estimate intracardiac chamber pressures [35].

A limitation of TTE is the significant technical skill that is required to obtain adequate images, which can be difficult even in the hands of experienced echocardiographers [35]. The acquisition of high-quality, clinically relevant images requires precise angulations of the TTE probe and knowledge of how to improve image acquisition. The transthoracic approach is noninvasive but often yields unsatisfactory images because of obstacles limiting the acoustic window [30, 36].

Transesophageal Echocardiography (TEE)

Transesophageal echocardiography involves the placement of the echo probe into the esophagus (or stomach) when the patient is sedated or unconscious, to view cardiac structures and assess function [37]. Transesophageal echocardiography generally provides clearer images of the endocardium, specifically the mitral valve, and is also superior at visualizing the left atrial appendage, aortic root, and interatrial septum.

Transesophageal echocardiography is a standard imaging tool used during cardiac surgery to facilitate the assessment of cardiovascular anatomy and function without surgical interruption [34, 37]. Furthermore, TEE is playing an increasing role during percutaneous valve interventions; positioning of closure devices for atrial septal defects, patent foramen ovale, and ventricular septal defects; and for electrophysiological procedures [38]. TEE is also used in the intensive care unit, to evaluate hypotensive patients, provide an accurate estimate of left ventricular function, and help assess preload [39]. A number of studies have also shown its safety among critically ill patients [36].

The Need for Simulation-Based Echocardiography Training

Extensive hands-on training is necessary to develop echocardiography skills [40]. For example, in the 2003 American College of Cardiology Foundation/American Heart Association (ACCF/AHA) Clinical Competence Statement on Echocardiography, the board suggested that minimum competence as an adult TTE echocardiographer requires 75 patient examinations and 150 echocardiogram interpretations [41]. Although the merit of establishing competence based on an absolute number of examinations as opposed to a competency-based approach is debatable, there is little doubt that higher levels of proficiency require increased training time and number of patient examinations.

With either echocardiography modality, there are common barriers to the development of proficiency. First, echocardiography requires significant cognitive and technical skills. The echocardiographer needs extensive knowledge of cardiac structure and function and must be able to visualize the heart in different acoustic planes. Parceled with this visual-spatial knowledge is the technical ability required to manipulate the ultrasound probe in order to produce quality images that are amenable to interpretation. Second, there is a paucity of formal training opportunities for learners to acquire these skills. Practice is limited because of patient and situational factors. For the awake patient in the echo laboratory undergoing TEE, there is limited time to practice given the potential physical discomfort. During surgical procedures in the operating room, practice is limited because of the need for prompt diagnosis, image interference from the use of electrocautery, and the initiation of cardiopulmonary bypass.

The traditional teaching model consists of the use of textbook reading and echocardiogram interpretation sessions combined with supervised practical experience in the echocardiography lab or in the operating room. In the case of TTE, trainees can learn from technicians and echocardiographers in a clinic or hospital setting and have the opportunity for independent practice. However, hands-on TEE experience is acquired during higher-risk clinical situations in the company of advanced echocardiographers. Regardless of modality (TTE or TEE), novices face a steep initial learning curve where basic image acquisition is dependent on simultaneously mastering probe manipulation.

Echocardiography simulators are ideally suited to overcome these learning obstacles. The simulator can accurately represent the various cardiac structures in an infinite number of image planes to help master the visualization of the heart during various manipulations of the probe. Some simulators have the ability to show real-time real-life and animated depictions of the heart relative to the ultrasound probe. There may be enhanced graphical features that allow the user to see the plane in which their echo beam is cutting through relative to the heart. Simulators can incorporate both normal and pathological findings. However, the ability to practice for extended periods of time in a nonthreatening zero-risk environment is arguably the most enticing feature of echo simulators. The use of simulation technology provides an opportunity to create a virtual training environment to offset the initial learning curve and shorten the eventual duration of training with patients [35].

Types of Echocardiography Simulators

At present there are three types of echo simulators designed to help improve the acquisition of knowledge and technical skill for TTE and TEE. These range from Web-based simulations to part-task heart models to part-task mannequins that incorporate virtual reality echocardiography.

Web-Based Echocardiography Simulators

The Web-based echocardiography simulators have been developed to aid in learning TEE. They use a 3-dimensional heart model, constructed from serial computer tomography slices of a real heart, with a virtual probe that the learner manipulates via their computer keyboard. These simulators allow the learner to visualize the cardiac structures in different planes, which is critical in the early stages of acquiring TEE knowledge [31, 40].

The effectiveness of one of these Web-based TEE simulators was evaluated with a pre- and posttest design [34]. After using the simulator for an average of 130 min, ten postgraduate fellows in anesthesia, cardiology, and cardiac surgery demonstrated a significant increase in their posttest scores on a video-based multiple choice test.

These simulators provide learners with the opportunity to develop structure identification and the visual-spatial correlation of echo plane and cardiac structure that is necessary for competency in TEE. Their benefits include the low cost (free) and the ability for the trainee to become familiar with the standard TEE views with the opportunity for unlimited practice. However, it remains to be seen if the knowledge gains translate to clinical practice.

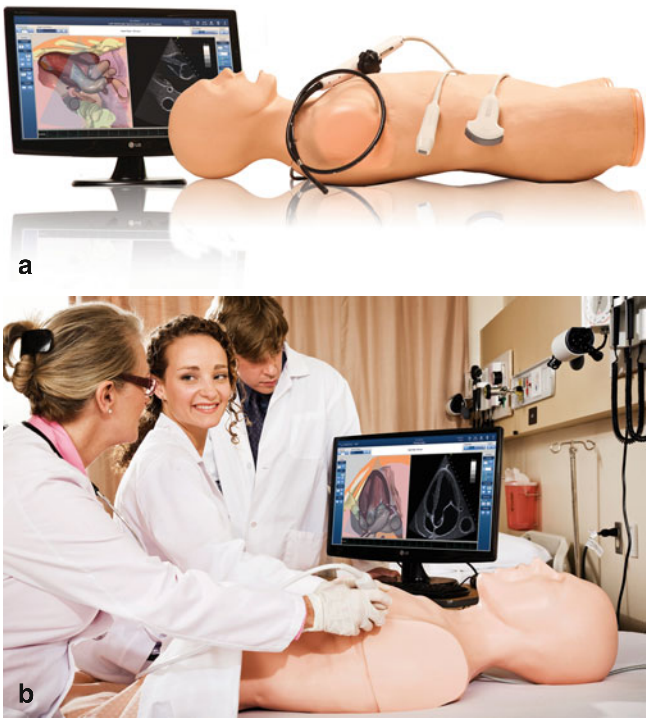

Fig. 18.3 (**a** and **b**) CAE Vimedix echocardiography simulator (Photo courtesy of CAE Healthcare ©2012 CAE Healthcare)

Part-Task Trainers

The simplest of the part-task trainers is an echocardiography simulator that consists of a full-body mannequin fitted with a physical, static, non-beating model of a human heart as well as lungs, ribs, and pericardial fluid (Blue Phantom™, USA). The heart model can be visualized and interrogated with either a TTE or TEE probe. This trainer allows the learner to become familiar with working a probe, working with the ultrasound machine, and obtaining images from all the relevant planes. However, because it is a static model, this trainer does not yield a realistic TTE experience for the operator.

The latest development in echocardiography part-task trainers is to combine a mannequin and dummy echo probe with virtual reality display of echocardiography images. In this setting, the learner moves the probe along the mannequin and views the echocardiographic images displayed on a computer screen. Manipulation of the probe changes the corresponding digital image, as in a real patient. These have been developed for both TTE and TEE, and their visual display combines both the echocardiographic image and a second screen displaying the three-dimensional virtual heart [35, 37, 42, 43]. Two commercially available simulators are CAE Vimedix (CAE Healthcare Inc, Montreal Canada) and HeartWorks (Inventive Medical Ltd, London, UK) (Figs. 18.3 and 18.4). The potential benefits of this type of trainer are the link between the transducer, the plane of the heart, and the echocardiographic image which may aid learners in acquiring knowledge and skills. The simulators have the capability to mimic both normal and abnormal cardiac exams (Fig. 18.5).

Aside from assessing user satisfaction, only one of these augmented simulators has been studied in a randomized, controlled trial to assess its educational effectiveness [44]. Fourteen first-year anesthesia residents were randomized either to a 90-min simulator-based teaching session with an instructor or to a control group consisting of self-study without the simulator. There was a statistically significant improvement in posttest scores for the simulator group compared to controls, on a video-based multiple choice questionnaire.

At the present time, the development of echocardiography simulators has outpaced the evaluation of their educational effectiveness. Theoretically, these simulators have many practical advantages to facilitate knowledge and skill acquisition. Acceptance of training in TEE and TTE with simulators has been shown to be very high among both novice and experienced echocardiographers [42, 43]. However, without studies comparing different approaches to echocardiography training, it is impossible to ascertain the relative benefits of the various simulation approaches. This is not to say that simulator-based training can or should replace the need for patient exposure, but it may supplement the traditional approaches to education and allow for development of basic knowledge and skills prior to practice on real patients. These technologies certainly hold the potential to address the barriers of time, patient exposure, and a steep learning curve that are associated with traditional echocardiography training methods.

Implementing a Noninvasive Simulation Curriculum

For any of the simulation modalities outlined in this chapter, a number of principles will facilitate the implementation of a simulation-based curriculum for noninvasive cardiology. First, a needs assessment of the learners is important, in order to develop appropriate learning objectives for the simulation sessions. This should take into account the current learning environments, with consideration of where the simulation modalities may best be used. For example, for novice learners of cardiac physical examination, adding time spent with simple heart sound or multimedia simulators prior to patient contact is a very efficient way of quickly improving learners' skills in heart sound recognition. The CPS can then be used to augment patient encounters that occur in the early clinical years, reinforcing the sounds heard at the bedside.

Second, the simulation-based modalities should be incorporated into the curriculum, as opposed to being stand-alone sessions. Third, whenever the simulation modality is in use, there may be a role for learners having time by themselves engaging in deliberate practice with the simulator. But of great importance is the presence of faculty, at some point in the learning session, to provide feedback and guidance to the learner. Finally, learning is consolidated if the session concludes with a skills test that requires the learner to achieve a certain level of competence before proceeding with the rest

Fig. 18.4 (**a** and **b**) HeartWorks echocardiography simulator (Photo courtesy of HeartWorks)

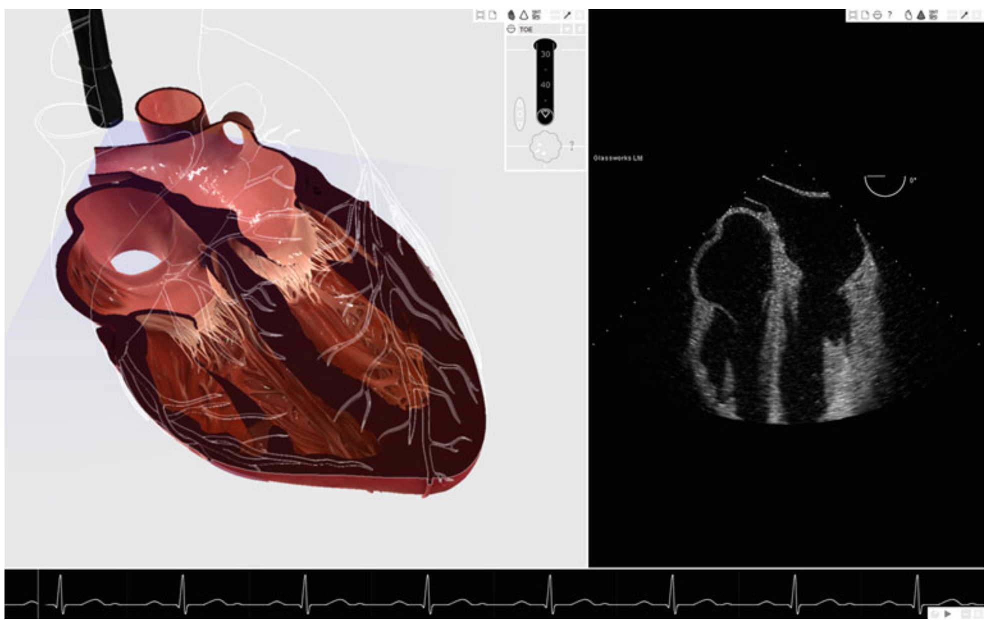

Fig. 18.5 Screenshot from HeartWorks TEE (Photo courtesy of HeartWorks)

of the curriculum. Layering different simulation modalities at different places in the curriculum can help learners scaffold their learning along a continuum of simple concepts to complex heart sounds.

Conculsion

Invasive cardiology skills are a vital to evaluate all patients specifically those with known cardiac disease. Auscultation has been shown to be under developed in our recent medical school graduates cardiac visualization skills seem to be supplanting Auscultation but this certainly require extensive training. Simulation may play a growing role in the aquisition and mastery of these auditory and visual skills.

References

1. Conn RD, O'Keefe JH. Cardiac physical diagnosis in the digital age: an important but increasingly neglected skill (from stethoscopes to microchips). Am J Cardiol. 2009;104(4):590–5.

2. Vukanovic-Criley JM, Criley S, Warde CM, et al. Competency in cardiac examination skills in medical students, trainees, physicians, and faculty: a multicenter study. Arch Intern Med. 2006;166(6):610–6.
3. Mangione S, Nieman LZ. Cardiac auscultatory skills of internal medicine and family practice trainees. A comparison of diagnostic proficiency. JAMA. 1997;278(9):717–22.
4. Mangione S, Nieman LZ, Gracely E, Kaye D. The teaching and practice of cardiac auscultation during internal medicine and cardiology training: a nationwide survey. Ann Intern Med. 1993;119(1):47.
5. Kern DH, Mainous III AG, Carey M, Beddingfield A. Simulation-based teaching to improve cardiovascular exam skills performance among third-year medical students. Teach Learn Med. 2011;23(1):15–20.
6. Stern DT, Mangrulkar RS, Gruppen LD, Lang AL, Grum CM, Judge RD. Using a multimedia tool to improve cardiac auscultation knowledge and skills. J Gen Intern Med. 2001;16(11):763–9.
7. Vukanovic-Criley JM, Boker JR, Criley SR, Rajagopalan S, Criley JM. Using virtual patients to improve cardiac examination competency in medical students. Clin Cardiol. 2008;31(7):334–9.
8. Gordon MS, Ewy GA, DeLeon AC, et al. "Harvey", the cardiology patient simulator: pilot studies on teaching effectiveness. Am J Cardiol. 1980;45(4):791–6.
9. Gordon MS, Ewy GA, Felner JM, et al. Teaching bedside cardiologic examination skills using "Harvey", the cardiology patient simulator. Med Clin North Am. 1980;64(2):305–13.
10. Bradley P. The history of simulation in medical education and possible future directions. Med Educ. 2006;40(3):254–62.
11. Passiment M, Sacks H, Huang G. Medical simulation in medical education: results of an AAMC survey. Washington: Association of American Medical Colleges; 2011. p. 1–48.
12. Ostfeld RJ, Goldberg YH, Janis G, Bobra S, Polotsky H, Silbiger S. Cardiac auscultatory training among third year medical students during their medicine clerkship. Int J Cardiol. 2010;144(1):147–9.
13. Horiszny JA. Teaching cardiac auscultation using simulated heart sounds and small-group discussion. Fam Med. 2001;33(1):39–44.
14. Barrett M, Kuzma M, Seto T, et al. The power of repetition in mastering cardiac auscultation. Am J Med. 2006;119(1):73–5.
15. Finley JP, Sharratt GP, Nanton MA, Chen RP, Roy DL, Paterson G. Auscultation of the heart: a trial of classroom teaching versus computer-based independent learning. Med Educ. 1998;32(4):357–61.
16. Roy D, Sargeant J, Gray J, Hoyt B, Allen M, Fleming M. Helping family physicians improve their cardiac auscultation skills with an interactive CD-ROM. J Contin Educ Health Prof. 2002;22(3):152–9.
17. Greenhalgh T. Computer assisted learning in undergraduate medical education. BMJ. 2001;322(7277):40–4.
18. Waugh RA, Mayer JW, Ewy GA, et al. Multimedia computer-assisted instruction in cardiology. Arch Intern Med. 1995;155(2):197–203.
19. Issenberg SB, Petrusa ER, McGaghie WC, et al. Effectiveness of a computer-based system to teach bedside cardiology. Acad Med. 1999;74(10 Suppl):S93–5.
20. Issenberg SB, Gordon MS, Greber AA. Bedside cardiology skills training for the osteopathic internist using simulation technology. J Am Osteopath Assoc. 2003;103(12):603–7.
21. Sverdrup Ø, Jensen T, Solheim S, Gjesdal K. Training auscultatory skills: computer simulated heart sounds or additional bedside training? A randomized trial on third-year medical students. BMC Med Educ. 2010;10(1):3.
22. AAMC. Effective use of educational technology in medical education. Washington: Association of American Medical Colleges; 2007. p. 1–19.
23. Verma A, Bhatt H, Booton P, Kneebone R. The Ventriloscope® as an innovative tool for assessing clinical examination skills: appraisal of a novel method of simulating auscultatory findings. Med Teach. 2011;33(7):e388–96.
24. Hatala R, Issenberg SB, Kassen BO, Cole G, Bacchus CM, Scalese RJ. Assessing the relationship between cardiac physical examination technique and accurate bedside diagnosis during an objective structured clinical examination (OSCE). Acad Med. 2007;82(10 Suppl):S26–9.
25. Criley JM, Criley D, Zalace C. Multimedia instruction of cardiac auscultation. Trans Am Clin Climatol Assoc. 1997;108:271–84; discussion 284–5.
26. Issenberg SB, McGaghie WC, Gordon DL, et al. Effectiveness of a cardiology review course for internal medicine residents using simulation technology and deliberate practice. Teach Learn Med. 2002;14(4):223–8.
27. Frost DW, Cavalcanti RB, Toubassi D. Instruction using a high-fidelity cardiopulmonary simulator improves examination skills and resource allocation in family medicine trainees. Simul Healthc. 2011;6(5):278–83.
28. Ewy GA, Felner JM, Juul D, Mayer JW, Sajid AW, Waugh RA. Test of a cardiology patient simulator with students in fourth-year electives. J Med Educ. 1987;62(9):738–43.
29. Butter J, McGaghie WC, Cohen ER, Kaye M, Wayne DB. Simulation-based mastery learning improves cardiac auscultation skills in medical students. J Gen Intern Med. 2010;25(8):780–5.
30. de Giovanni D, Roberts T, Norman G. Relative effectiveness of high- versus low-fidelity simulation in learning heart sounds. Med Educ. 2009;43(7):661–8.
31. Fraser K, Wright B, Girard L, et al. Simulation training improves diagnostic performance on a real patient with similar clinical findings. Chest. 2011;139(2):376–81.
32. Kneebone RL, Kidd J, Nestel D, et al. Blurring the boundaries: scenario-based simulation in a clinical setting. Med Educ. 2005;39(6):580–7.
33. McGaghie WC, Issenberg SB, Petrusa ER, Scalese RJ. A critical review of simulation-based medical education research: 2003–2009. Med Educ. 2010;44(1):50–63.
34. Jerath A, Vegas A, Meineri M, et al. An interactive online 3D model of the heart assists in learning standard transesophageal echocardiography views. Can J Anaesth. 2011;58(1):14–21.
35. Matyal R, Bose R, Warraich H, et al. Transthoracic echocardiographic simulator: normal and the abnormal. J Cardiothorac Vasc Anesth. 2011;25(1):177–81.
36. Heidenreich PA, Stainback RF, Redberg RF, Schiller NB, Cohen NH, Foster E. Transesophageal echocardiography predicts mortality in critically ill patients with unexplained hypotension. J Am Coll Cardiol. 1995;26(1):152–8.
37. Bose R, Matyal R, Panzica P, et al. Transesophageal echocardiography simulator: a new learning tool. J Cardiothorac Vasc Anesth. 2009;23(4):544–8.
38. Flachskampf FA, Badano L, Daniel WG, et al. Recommendations for transoesophageal echocardiography: update 2010. Eur J Echocardiogr. 2010;11(7):557–76.
39. Tousignant CP, Walsh F, Mazer CD. The use of transesophageal echocardiography for preload assessment in critically ill patients. Anesth Analg. 2000;90:351–5.
40. Kempny A, Piórkowski A. CT2TEE – a novel, internet-based simulator of transoesophageal echocardiography in congenital heart disease. Kardiol Pol. 2010;68(3):374–9.
41. Quiñones MA, Douglas PS, Foster E, et al. ACC/AHA clinical competence statement on echocardiography. J Am Coll Cardiol. 2003;41(4):687–708.
42. Weidenbach M, Wild F, Scheer K, et al. Computer-based training in two-dimensional echocardiography using an echocardiography simulator. J Am Soc Echocardiogr. 2005;18(4):362–6.
43. Weidenbach M, Drachsler H, Wild F, et al. EchoComTEE – a simulator for transoesophageal echocardiography. Anaesthesia. 2007;62(4):347–53.
44. Bose RR, Matyal R, Warraich HJ, et al. Utility of a transesophageal echocardiographic simulator as a teaching tool. J Cardiothorac Vasc Anesth. 2011;25(2):212–5.