Short Communication

Using Virtual Patients to Improve Cardiac Examination Competency in Medical Students

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ABSTRACT

Background: Cardiac examination (CE) skills are in decline. Most prior studies employed audio recordings, evaluating only one aspect of CE (i.e., auscultation) that precluded correlation with visible observations. To address these deficiencies, we developed a curriculum using virtual patient examinations (VPEs); bedside recordings of patients with visible and audible cardiovascular findings presented as interactive multimedia.

Hypothesis: The purpose of this study was to evaluate whether VPEs improve CE skills, and whether any improvements are retained. We assessed CE competency overall and in 4 categories: inspection, auscultation, knowledge, and integration of audio and visual skills.

Methods: Students ($n = 24$) undergoing the 8-wk Internal Medicine (IM) clerkship rotation and receiving supervised instruction with VPEs (intervention group) were compared with students ($n = 58$) undergoing IM clerkship rotation without supplemental CE instruction (control group). The groups were tested at the beginning and the end of their rotations.

Results: The Intervention group improved significantly in overall mean scores: from 58.7 to 73.5 ($p = 0.0001$). The Control group did not improve: from 60.1 to 59.5 ($p = 0.788$). The Intervention group improved inspection, auscultation, and knowledge (all $p \leq 0.02$); control group showed no improvement. Fourteen months after the study, 8 students from the intervention group were re-tested and mean scores improved further to 83.6 without additional intervention ($p = 0.004$); controls showed improvement on re-testing, but it was not significant: 65.0 ($p = 0.464$).

Conclusions: Cardiac examination inspection, auscultation, and knowledge improved by using VPEs to the level of cardiology fellows. These skills were retained 1 y later. The teaching and testing tools emphasizing the bedside use of both sight and sound, identify which CE skills needed improvement and additional training.

Key words: cardiac examination skills, competency, multimedia teaching and testing, virtual patients examinations, heart sounds

Introduction

Cardiac examination (CE) is an essential physical examination skill. Numerous studies, however, continue to document deficiencies in the CE at all levels of training.[1–3] Repetitive listening to synthesized sounds has been reported to improve recognition of heart sounds and murmurs.[4,5] However, by using only listening skills one is not taking advantage of visual findings that provide timing of audible events that add to diagnostic information.

Others have shown that perception in 1 sensory modality is enhanced by others, so that what one hears is influenced by what one sees, and vice versa.[6] For cardiac auscultation, it is easier to place acoustical events in systole or diastole when inspecting an arterial pulse or precordial impulse, just as it is easier to see these pulsations while listening. The repetitive nature of the cardiac cycle permits cross-correlation between audible and visible events, comparable to watching a repeating instant replay in baseball where the timing of the arrival of the ball in the first baseman's glove relative to the runner's arrival at the base can be scrutinized repeatedly to establish whether the runner is safe or out. Likewise, CE skills require processing multiple senses simultaneously, and cannot be effectively taught with textbooks or by using listening skills in isolation. In fact, CE

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skills are best acquired by exposure, practice, and testing for competence. Since CE skills are themselves a multimedia experience,[1,7–9] computer programs employing audiovisual technology are ideally suited to this educational challenge.

Medical students traditionally start clinical rotations in their third year, but learning bedside CE skills depends upon the availability of suitable patients, and appropriate supervision and teaching. In addition to clerkship rotations, current teaching methods range from classroom lectures and courses,[10] and discussion and audiotape,[4] to heart sound simulators[11] and computer-assisted instructions.[12] None of these methods have been widely adopted or shown to be clearly superior.

To address these deficiencies, we have used a series of interactive, multimedia teaching programs with actual patients recorded at bedside: virtual patient examinations (VPEs). For competency testing, we used a CE test that evaluates not only auditory skills (i.e., auscultation), but additional subcategories of CE competency: visual skills (i.e., inspection), knowledge of cardiac anatomy and physiology, and integration of auditory and visual skills.[1] In evaluating CE competency across the medical training spectrum, from medical students and residents to cardiology fellows, CE skills reached a plateau in third-year medical students (MS3) and did not improve thereafter.[1] An important exception were cardiology fellows who were the highest performing group overall (i.e., experts) and excelled in all 4 subcategories of competency tested, especially visual skills.

The purpose of this study was to evaluate a novel CE curriculum for MS3 that used VPEs in clinical teaching. Our goal was to determine if teaching MS3 with these innovative programs that closely mimic bedside examination would bring them to the level of the experts, as compared with their peers who received ward rotation without structured CE teaching. We compared group performances overall and across 4 subcategories of CE competency. Our second goal was to asses the impact of this new curriculum on long-term retention. We hypothesized that by using more realistic training, long-term retention would be improved.

Methods

Study Groups and Design

The MS3 intervention group (ward rotation and structured training with VPE) consisted of 24 medical students taking the required 8-wk internal medicine (IM) clinical clerkships. While enrolled in the clerkships at their base teaching hospital, they attended the 90 min “Operation Heart Sounds” classes each Saturday morning for 8 wk, taught by John Michael Criley. Students brought stethoscopes to class in order to hear actual heart sounds through individual speaker pads, while they observed either the patient being examined or dynamic graphics depicting cardiac and valvar action on a projection screen. All students were tested at the beginning and end of their 8-wk IM clinical clerkship. A subset of students (n = 8) was re-tested on their last week of medical school, over a year later, to assess long-term retention.

The MS3 control group (ward rotation and no structured training with VPE) consisted of 58 students undergoing 8-wk IM clinical clerkships, in which they examined and presented patients to the resident and the attending physicians several times a week. Fifty-eight students were tested at the beginning, and 42 students were present to take the test at the end of their 8-wk IM clinical clerkship. A subset of students (n = 9) was retested during their fourth year of medical school, over a year later, to assess long-term retention.

The IM clerkships for both intervention and control groups, provided random exposure of MS3s to 20–50 patients, many with cardiac physical findings, under the supervision of house officers and attending physicians.

Educational Intervention

CE Curriculum: The CE curriculum used in the intervention featured VPEs; interactive multimedia teaching programs of actual patients filmed at bedside.[13–16] The term virtual refers to transferring the bedside findings to a computer in order to share the same patient encounter with a wider audience than would be practical at the actual bedside. These programs integrate actual heart sounds with visual reference signals or computer graphics animations, and are designed to teach eye/ear integration as well as demonstrate the causation of sounds and murmurs. For video and audio scenes of actual patients, the stethoscope can be moved to multiple listening locations, and history and pertinent laboratory studies (i.e., chest x-ray, [ECG] echocardiogram, etc.) are available. The VPEs permit the examiner to move the stethoscope over the precordium while observing pulses, respiration, and/or postural maneuvers. The VPEs used for teaching are different than those used for testing of CE competency.

We previously recommended that VPEs be used with first- and second-year medical students to enable them to distinguish between venous and arterial pulsations, and to make them accustomed to integrating sight and sound.[1] We further believe that this multimedia training should be reinforced in third- and fourth-year students by using visual and/or palpable information to distinguish between systole and diastole with multimedia programs, and during patient encounters.[1] Since MS3s received basic CE training in their second year, our curriculum intended to repeat these basics and to build upon prior learning at a level appropriate for MS3.

We obtained institutional review board (IRB) approval and organized protected time for classroom-based instruction for MS3. Training consisted of 8 structured workshops (12 h total) using the heart sounds teaching materials listed above, preceded and followed by the competency test.

The learning objectives of the intervention are outlined in Table 1. Accordingly, the 8 sessions were comprised of functional anatomy (intracardiac pressures, sounds, dynamic images, and scenes of patients) of the normal heart, mitral valve lesions (2 sessions), aortic valve lesions (2 sessions), congenital heart diseases, cardiomyopathies, and pericardial diseases.

The CE Test: The CE test is a reliable, 50-question, interactive, multimedia computer-based test, described and validated previously.[1,17] Students were not asked for a diagnosis, but rather for bedside findings (e.g., an ejection sound, a mid-systolic murmur, or a bounding carotid pulse). The first half of the test used computer animations and hemodynamics synchronized with actual heart sounds; the second half used audiovisual heart sounds recordings from patients whose diagnoses were confirmed by ECG. Looking and listening simultaneously to determine timing of cardiac events was required in 26 questions. The same test was used as a pre- and post-test for both groups. There were 16 multiple-choice (4 options) and 34 true/false questions, with 2 points assigned for correct answers, negative points for incorrect answers, and zero points for any unanswered questions. This scoring system thus yields 100 points if all questions are correctly answered.

Testing: The CE testing was described previously.[1] Briefly, students listened through stethoscopes connected to individual speaker pads while observing video of the patient on a computer monitor display or digitally projected image. The examination typically took approximately 25 min. Answer sheets were collected and kept in a secure file. All tests were scored by 2 independent graders and were confirmed by automated scoring on the computer.

TABLE 1: Outline of learning objectives for the intervention study

Anatomy of precordium and cervical vasculature
Identification of pulsations
Causation and propagation of sounds and murmurs
Identification of and causation of sounds
Identification and (usual) causation of murmurs
Identification skills
Pulsations in normal
Sounds in normal
Extra sounds and splitting of sounds
Murmurs
Using visual cues to aid listening
Using auditory cues to aid observing
Interpretation skills
History
Examination

Statistical Analysis

We used paired t tests where baseline and post-training scores could be matched to the same student and independent (Student's) t test for unpaired scores. To test for differences in CE competency between intervention and control groups, we compared mean scores using the independent (Student's) t test for either equal or unequal group variances, as appropriate. We used the nominal $p<0.05$ level for statistical significance, and did not adjust the p-value for computing multiple comparisons. Analyses were performed with SPSS statistical software, version 13.0 (SPSS, Inc., Chicago, Ill., USA).

Role of Funding Sources

The funding source was not involved in the design, conduct, or reporting of the study or decision to submit the manuscript for publication.

Results

Conventional Ward and Multimedia Training

For the intervention group, the post-training mean score (73.5±8.4, mean±standard deviation [SD]) improved from baseline (58.7±14.0, $p = 0.0001$). Audio, visual, and knowledge subcategories of CE competency showed similar improvements (Table 2, all $p\leq 0.02$). Integration of audiovisual skills began higher than the other subcategories and remained unchanged. The difference between intervention and control groups at post-testing was also significant ($p = 0.0003$) (Figure 1).

Fourteen months later, 8 students from the intervention group responded to a request for re-testing. The mean score at retention (83.6±7.0) was significantly higher than baseline (58.7±14.0, $p = 0.00004$). Moreover, improvements in audio, visual, and knowledge skills were retained ($p\leq 0.005$). Furthermore, the mean score at retention (83.6±7.0) continued to improve after post-training (73.5±8.4), without any additional structured intervention ($p = 0.004$). There was particular improvement in visual skills ($p = 0.025$).

Students responded very positively to this innovative testing and teaching format, with a large majority stating that VPEs were impressive and highly realistic, and that the test was challenging but fair.

Conventional Ward Training Only

At baseline, mean CE competency scores were not significantly different for control or intervention groups ($p = 0.704$). For the control group, the post-training mean scores (59.5±15.4) did not change from baseline (60.1±15.4, $p = 0.788$). Similarly, audio, visual, knowledge,

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TABLE 2: Intervention group: mean overall CE competency and 4 subcategories scores

					①			②	③
	Pre-test (n = 24)		Post-test (n = 24)		Paired *t* test	Retention (n = 8)		*t* test	*t* test
Intervention	Mean % (SD)	95% CI	Mean % (SD)	95% CI	p-value	Mean % (SD)	95% CI	p-value	p-value
Overall score	58.7 (14.0)	53.1–64.3	73.5 (8.4)	70.1–76.8	0.0001	83.6 (7.0)	78.8–88.5	0.00004	0.004
Inspection	66.1 (21.9)	57.3–73.7	81.8 (9.3)	78.1–85.5	0.002	91.1 (10.6)	83.7–98.4	0.004	0.025
Auscultation	*69.7 (18.1)*	*62.5–77.0*	*85.4 (9.2)*	*81.7–89.1*	*0.005*	*90.5 (10.2)*	*83.5–97.5*	*0.005*	0.196
Knowledge	67.1 (13.5)	61.7–72.5	77.5 (16.3)	71.0–84.1	0.02	86.1 (9.8)	79.3–92.	*0.001*	0.172
Integration	80.8 (17.7)	69.8–85.3	83.4 (11.6)	78.7–88.0	0.555	88.0 (12.3)	79.4–96.5	0.297	0.347

Abbreviations: CE = cardiac examination; CI = confidence interval; SD = standard deviation. ① Compares pre-test and post-test. ② Compares pre-test and retention. ③ Compares post-test and retention.

TABLE 3: Control group: mean overall CE competency and 4 subcategories scores

					①			②	③
	Pre-test (n = 58)		Post-test (n = 42)		*t* test	Retention (n = 9)		*t* test	*t* test
Control	Mean % (SD)	95% CI	Mean % (SD)	95% CI	p-value	Mean % (SD)	95% CI	p-value	p-value
Overall score	60.1 (15.4)	56.1–64.0	59.5 (15.4)	54.9–64.2	0.788	65.0 (16.6)	54.1–75.9	0.464	0.377
Inspection	69.8 (26.3)	63.0–76.6	68.8 (24.3)	61.5–76.2	0.056	65.1 (27.8)	46.9–83.2	0.564	0.62
Auscultation	73.9 (14.4)	70.2–77.6	74.3 (14.7)	69.8–78.7	0.841	79.7 (14.1)	70.5–89.0	0.254	0.262
Knowledge	64.2 (16.0)	60.1–68.3	64.0 (16.1)	59.2–68.9	0.192	71.6 (26.1)	54.5–88.7	0.752	0.243
Integration	79.1 (21.5)	73.6–84.7	78.6 (21.4)	72.1–85.1	0.44	77.4 (13.5)	68.6–6.2	0.794	0.819

Abbreviations: CE = cardiac examination; CI = confidence interval; SD = standard deviation. ① Compares pre-test and post-test. ② Compares pre-test and retention. ③ Compares post-test and retention.

and integration skills remained the same (Table 3) (all p-values$\geq$0.06) (Figure 1).

The following year, 9 fourth year medical students agreed to re-take the test. The mean score at retention (65$\pm$16.6) was not significantly higher than baseline (60.1$\pm$15.4, p$\geq$0.464), and there was no change in scores of any of the subcategories (all p-values$\geq$0.254). Similarly, when compared with post-training, the mean scores and subcategories did not change (all p-values$\geq$0.254).

Discussion

Our study demonstrates that teaching with VPEs dramatically improves MS3 overall CE competency scores to a level previously measured in cardiology fellows.[1] No significant improvement was seen in the control group of contemporaneous classmates who received only traditional IM clerkship instruction.

Although the problem of declining CE skills is well documented,[1–3,8] effective teaching methods are scarce. Students are expected to learn CE skills from patient encounters during their clinical clerkships. A problem in evaluating traditional clerkships has been the absence of a standardized, reproducible, and objective tool to evaluate specific CE skills learned by students.

The value of this study is the reporting of a CE measurement tool that evaluated both an innovative and current clerkship curricula. Unlike methods that focus on cardiac auscultation only,[4,5,10–12] the software used in this study teaches and tests overall CE skills and its

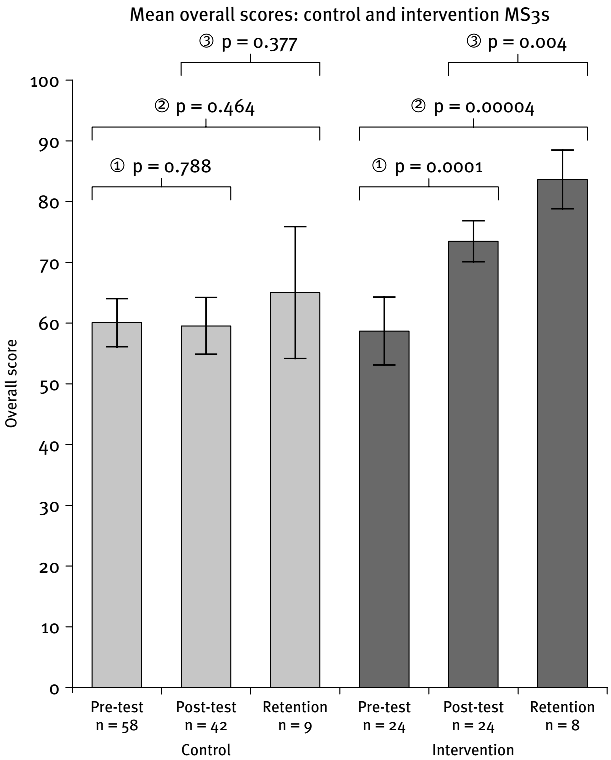

Figure 1: Mean test scores for CE competency for 2 groups of MS3s: control group and intervention group. Both groups were tested before their rotation, at the end of their 8-wk clerkship rotation, and more than a year later to test for retention. Error bars represent 95% confidence intervals.

subcategories, providing breakdowns of the specific CE skills that improved or did not. Experts excelled in all 4 of these CE subcategories, but especially in visual skills.[1]

Auscultation is only 1, and is often overemphasized,[8] of the skills of CE. When taught in isolation, it is very likely to be performed in isolation, that is, without incorporating visual or palpable cues from the patient. We observed previously that students and trainees who failed to time what they heard with visible pulsations tended to identify every murmur and extra sound they encountered as systolic.[1] The clinical consequence is that diastolic murmurs, which are always pathologic, may be underdetected. Programs that provide training in only auscultation skills will not address this learning deficit, and may explain why the CE test scores across all training levels reach a plateau by MS3, and do not improve thereafter.[1] Indeed, as shown in this study, students who completed their medicine clerkships did not improve overall CE competency, nor in any of the subcategories.

While the intervention group was exposed to a known spectrum of cardiac findings through VPEs, we were unable to measure the extent or depth of exposure either the intervention or control group received through patient encounters. On the basis of our results, it appears that students completing traditional clerkship rotations are not benefiting from patient encounters to acquire and improve these skills.

In contrast, the intervention group used VPEs to complement the patient encounters received during their clerkship, providing a standardized exposure to a spectrum of important cardiac findings. In addition, these findings were correlated with changes in anatomy and hemodynamics that occur with disease, to create a memorable image of the cardiac cycle for each patient encounter. Not only did their overall scores improve by using this comprehensive approach, but they also improved scores in inspection, auscultation, and CE knowledge. Results from the small subset who agreed to taking the test again a year later suggest that their learning may continue after the intervention in ways that the control group did not.

While others have shown that computer-aided instruction is as effective as more traditional methods,[18] our study suggests that this method is both more effective and more efficient. The multimedia programs used in this study present an array of cardiac physical findings in a format very similar to the bedside examination. However, unlike bedside examination, these programs can be used at the teacher's (or student's) own convenience, allowing for review and repetition. For example, the post-extra systolic augmentation of a systolic murmur is dependent upon a transient event (a premature ventricular complex) that may or may not occur during bedside teaching. In contrast, a VPE can repeat this finding as many times as necessary.

Limitations

The programs used for the intervention group were available in the medical school library for all students, including the control group. Although we do not know whether students in the control group used the programs on their own, we did not observe any improvement in mean scores. In contrast, the improvement observed in the intervention group may have been instructor dependent. Finally, the quality of teaching attendings may have varied among the medicine rotations, as well as the quality and quantity of patients with cardiac findings.

Conclusion

With the above limitations noted, this study contributes to the ongoing efforts in improving the teaching and testing of CE competency. This study showed that training with VPEs yields superior test scores than conventional IM clerkship training alone. There was no improvement in CE competency during the third year of medical school when structured programs were not offered. While knowledge can be learned from books, the audio and visual skills of CE competency can be learned and tested for at the bedside or with VPEs. Further studies will determine whether these skills will translate into better diagnostic ability and

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more economical practice patterns when dealing with real patients.

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References

1. Vukanovic-Criley JM, Criley SR, Warde C, Boker J, Guevara-Matheus L, et al.: Competency in cardiac examination skills in medical students, trainees, physicians and faculty: A multicenter study. *Arch Intern Med* 2006;166:610–616
2. Feddock CA: The lost art of clinical skills. *Am J Med* 2007; 120(4):374–378
3. Zoneraich S, Spodick DH. Bedside science reduces laboratory art: appropriate use of physical findings to reduce reliance on sophisticated and expensive methods. *Circulation* 91
4. Horiszny JA: Teaching cardiac auscultation using simulated heart sounds and small-group discussion. *Fam Med* 2001;33:39–44
5. Barret MJ, Kusma MA, Seto TC, Richards P, Mason D, et al.: The power of repetition in mastering cardiac auscultation. *Am J Med* 2006;119(1):73–75
6. Shimojo S, Shams L: Sensory modalities are not separate modalities: plasticity and interactions. *Curr Opin Neurobiol* 2001;11(4):505–509
7. Criley JM, Criley D, Zalace C: Multimedia instruction of cardiac auscultation. *Trans Am Clin Climatol Assoc* 1996;108:271–284; discussion 284–285
8. Conn RD: Letter to the Editor re: Cardiac auscultatory skills of physicians-in-training: comparison of three English-speaking countries. *Am J Med* 2001;111(6):505–506
9. Gregoratos G, Miller AB: 30th Bethesda conference: The future of academic cardiology. Task force 3: teaching. *J Am Coll Cardiol* 1999;33(5):1120–7.16
10. Mangione S, Peitzman SJ, Gracely E: Nieman, LZ creation and assessment of a structured review course in physical diagnosis for medical residents. *J Gen Intern Med* 1994;9:213–218
11. Champagne MT, Harrell JS, Friedman BJ: Use of a heart sound simulator in teaching cardiac auscultation. *Focus Crit Care* 1989;16:448–456
12. Stern DT, Mangrulkar S, Gruppen LD, Lang AL, Grum CM, et al.: Using a multimedia tool to improve cardiac auscultation knowledge and skills. *J Gen Intern Med* 2001;16(11):763–769
13. Criley JM, Criley DG, Zalace C: The physiological origins of heart sounds and murmurs: the unique interactive guide to cardiac auscultation. *Blaufuss Multimedia*, Little Brown (CD) 1995
14. Criley JM. CE interactive. *Blaufuss Multimedia*, Little Brown (CD) 2000
15. Criley SR, Criley DG, Criley JM: Beyond heart sounds: An interactive teaching and skills testing program for cardiac examination. *Comput Cardiol* 2000;27:591–594
16. *Blaufuss Medical Multimedia Laboratory: Heart Sounds Tutorial*. Available at: http://www.blaufuss.org/tutorial Accessed May 19th 2006
17. Warde C, Criley S, Criley D, Boker J, Criley J: *Validation of a Multimedia Measure of Cardiac Physical Examination Proficiency* Boston, MA: AAMC Group on Educational Affairs, 2004; RIME Summary Presentations, November
18. Lyon HC Jr, Healy JC, Bell JR, O'Donnell JF, Shultz EF, et al.: PlanAnalyzer, an interactive computer-assisted program to teach clinical problem solving in diagnosing anemia and coronary artery disease. *Acad Med* 1992;67:821–828