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Using High-Fidelity Patient Simulation and an Advanced Distance Education Network to Teach Pharmacology to Second-Year Medical Students

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The feasibility and acceptance of an Advanced Distance Education Network (ADEN) in bringing the simulated operating room (OR) to second-year medical students learning the pharmacology of anesthetic drugs is reviewed. A MedSim-Eagle (Binghamton, NY) full-scale mannequin simulator was used. Using an ADEN, students were linked in real time to a simulated OR where the anesthesiologist instructor was using a MedSim-Eagle patient simulator to present for discussion the physiologic effects of volatile anesthetics on cardiac output (CO), heart rate (HR), mean arterial pressure (MAP), and systemic vascular resistance (SVR). The use of simulation to present basic science principles of isoflurane and halothane's effect on CO, HR, MAP, and SVR in a clinical setting via an ADEN is feasible. Student acceptance of this method of education is high, as measured by a post-exercise survey. Ninety-five percent of students felt this exercise was a valuable use of their time; 93% felt the ADEN-delivered clinical simulation presentation contributed to their understanding of the pharmacology of anesthesia. Eighty-three percent of students preferred this integrated clinically oriented review to a didactic review of the material, and 92% of students who had experienced previous small group hands-on session simulation felt the ADEN-delivered session was the same or better.

Keywords: Anesthesiology; anesthetics, pharmacology of; distance education; simulation.

Study Objectives

The concepts taught in the basic science years of medical school are often difficult for the students to retain long enough to apply them during their clinical years. Many schools have tried to integrate the 4 years by bringing early clinical experiences to students with courses on patient interviewing and basic physical examination skills. More recently, problem-based learning sessions, which integrate clinical scenarios with the basic science topics being discussed,

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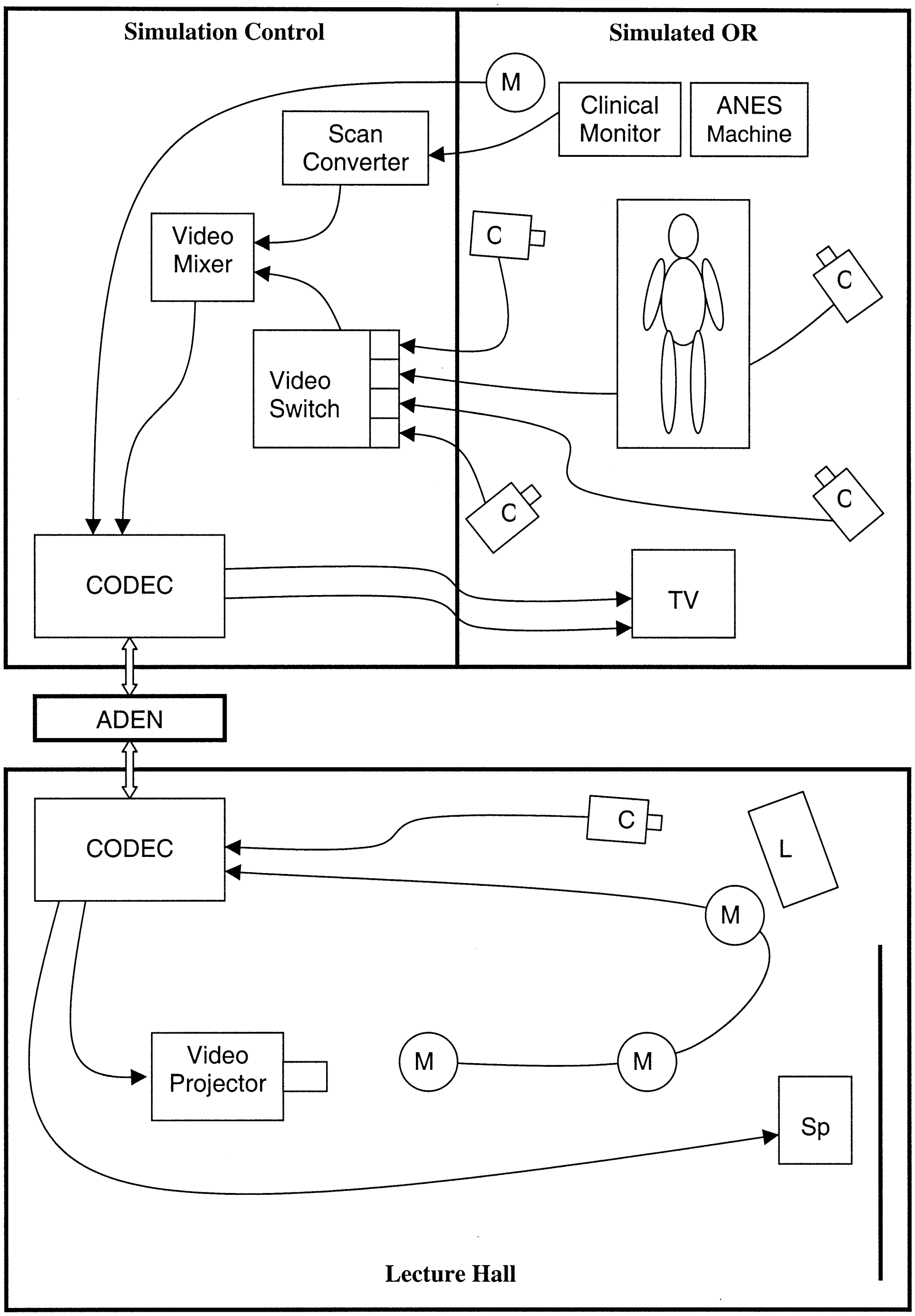

Figure 1. Schematic of A/V technology and ADEN connections: C = camera, M = microphone, TV = television, L = lectern, Sp = speaker.

have been added to the first 2 years of medical education.[1,2] The Uniformed Services University of the Health Sciences (USU), in addition to problem-based learning courses, uses high-fidelity patient simulators to help bridge the gap from basic sciences to clinical experience.[3]

At USU, anesthesiologists teach a 2-hour course, The Pharmacology of Inhalational Anesthetics, during the second year of the basic sciences. Students are expected to retain lessons learned from this lecture and recall them during their core rotation in Anesthesiology in their third year. It is often more than 15 months before students see these concepts again in the operating room (OR). Ideally, students would be immediately taken from the classroom to the OR to see clinical examples of the concepts presented during the didactic lectures. However, moving more than 100 students from the classroom to the OR is

Table 1. Advanced Control* Settings Used to Achieve Hemodynamic Values for Each Agent at 1 and 2 MAC

	Baseline	Halothane 1 MAC	Halothane 2 MAC	Isoflurane 1 MAC	Isoflurane 2 MAC
Baroceptors	0.0	0.9	1.0	0.8	0.8
Contractility	0.0	−0.6	−1.0	−1.0	−1.0
Peripheral resistance	−0.1	−0.2	−0.4	−0.6	−0.8
Capacitance	0.0	150	300	100	200

All other setting remained at baseline.

*Advanced controls are 13 physiologic variables available to the operator of the MedSim-Eagle simulator to increase or decrease the value or sensitivity of each variable. These advanced controls can be used to change the patient's physiology while the patient is running.

impractical. Another option is to take students to a simulated OR using high-fidelity patient simulators. Small-group education, however, is time-consuming and labor intensive for clinical instructors and simulation laboratory personnel. A final option is to use simulation and distance education to bring clinical environments to the lecture hall for an interactive large group session. Our objective was to test the feasibility of using an ADEN to deliver simulation interactively in a large group format, and assess the learners' experience via a satisfaction questionnaire. This goal was accomplished by reviewing lecture material on the effects of halothane and isoflurane at one and two MAC (minimal alveolar concentrations) on cardiac output (CO), heart rate (HR), mean arterial pressure (MAP), and systemic vascular resistance (SVR).

Technical Setting

A MedSim-Eagle full-scale mannequin-based patient simulator was used to simulate the physiologic responses to the changes in anesthetic agents and concentrations. The connections between the simulation laboratory and the lecture hall are shown in *Figure 1*. An analog S-video signal, selected from one of four cameras, was combined with the video signal from a clinical monitor (Philips M1094B, Philips Instruments, Boston MA) using a scan converter (AVerkey 500 Pro, AverMedia, Milpitis, CA), and a video mixer (Videonics MXPro, FOCUS Enhancements, Campbell, CA). This combined signal was encoded with a ViewStation codec (Polycom, Milpitas, CA) and sent through a twisted-pair Ethernet cable to an Ethernet switch (Omnicore 5010, Alcatel, Plano, TX), which has a maximum transmission rating of 100 Mbits/sec for each twisted-pair port. Another 100 Mbits/sec link connected the other codec to the same switch.

The digitized, IP-encoded video stream was sent at 768 Kb/sec to the second ViewStation in the lecture hall, where it was decoded, and the recreated analog video signal projected in the lecture hall. Audio signals were delivered to the lecture hall *via* the same devices and network as the video signal. Audio and video from the lecture hall were also collected and transmitted back to the simulation facility using the bidirectional transmission audio and video capabilities of the codecs and ADEN. Because the low data rate limitation of the employed encoder reduced the overall image clarity of the clinical monitor's hemodynamic calculation table, the pan/zoom function of the scan converter was used to enlarge that segment of the images in the simulation facility before encoding.

Target Audience

A total of 110 second-year medical students were present for the 1 hour 45 minute lecture block followed by 15 minutes of remote interactive simulation to teach the pharmacology of inhalational anesthetics. The target audience also included nurse anesthetist trainees and pharmacy graduate students.

Simulation Script

The patient simulator software was set for a "normal, healthy" patient. Advanced Controls, the MedSim-Eagle simulator adjustments that modify physiologic settings, were then used (*Table 1*) to obtain reproducible results for CO, HR, MAP, and SVR that correlated with published data for 1 and 2 MAC for isoflurane and halothane[4] (*Table 2*). Advanced Controls ensured superior reproducible results with speed and accuracy compared with simulated virtual agents and eliminated the scavenging concerns for real agents. Because these were beginning students, time constants to reach equilibrium were felt to be less important than reproducible end points matching textbook results.

Students were introduced to the simulated patient who was present for an elective laparoscopic cholecystectomy. He had "consented" to our placement of the necessary monitors and to demonstrating the educational material after his induction and before his planned procedure. Following placement of routine monitors, the patient was preoxygenated with 100% oxygen and underwent a standard induction followed by intubation and mechanical ventilation. A pulmonary artery catheter (PAC) was inserted *via* a right internal jugular introducer for hemodynamic measurements and calculations. Students were instructed by the clinical specialist that a PAC is not a routine monitor for this case, but was being placed to allow collection of the data necessary to measure and calculate CO, HR, MAP, and SVR. A clinical monitor view (*Figure 2*) showing wedging of the PAC was demonstrated to the students *via* the ADEN, and then the students were

Table 2. Pharmacology of Anesthesia Data Collection Sheet with Results

		1	2	3	4	5
Variable	**Units**	**Baseline**	**Halothane 1 MAC**	**Halothane 2 MAC**	**Isoflurane 1 MAC**	**Isoflurane 2 MAC**
Cardiac output	L/min	5.24	4.39	3.60	4.86	4.44
Heart rate	bpm	73	75	75	81	84
Mean arterial pressure	mmHg	92	76	56	59	44
Stroke volume	mL	71	59	48	60	53
Systemic vascular resistance	$DynSec/cm^5$	1,404	1,384	1,244	971	792

Objectives: Understanding the cardiovascular effects of volatile anesthetics; understanding the differences between halothane and isoflurane; and to educate through Distance Education.

returned to a room view. During the simulation the students recorded CO, HR, MAP, SV, and SVR values from the Philips clinical monitor at baseline, and at 1 and 2 MAC (*Table 2*). After changing the concentration of the volatile anesthetic agents, but before results were obtained, the students were questioned on the predicted outcomes based on the lecture material. Following student predictions, COs were obtained. Hemodynamic calculations were performed by the clinical anesthesiologist using the clinical monitor's software and the students' predictions were compared to the measured data (*Figure 3*). Students did not perform the calculations themselves. Central venous pressure (CVP) was set to zero for all calculations and was not presented to the students. This was because of the inability to reliably recreate CVP data comparable to the published literature[4] and maintain accurate results for CO, HR, MAP, and SVR. At the conclusion of the session, the students again reviewed the key teaching points and differences in volatile anesthetics and how they affect CO, HR, MAP, and SVR. Other questions were entertained and discussion with the clinician was facilitated. The students were asked to complete a questionnaire to help determine their perception of the value of the laboratory session, its contribution to their understanding of the pharmacology of anesthesia, and the quality of the ADEN technology. Students who had previously participated in the first-year physiology small-group simulation laboratory were asked if they preferred the small group session or ADEN for future simulation exercises.

Assessment of Effectiveness

Results for cardiovascular effects of halothane and isoflurane at 1 and 2 MAC are shown in *Table 2*. Student responses to the questionnaire are listed in *Table 3*. Ninety

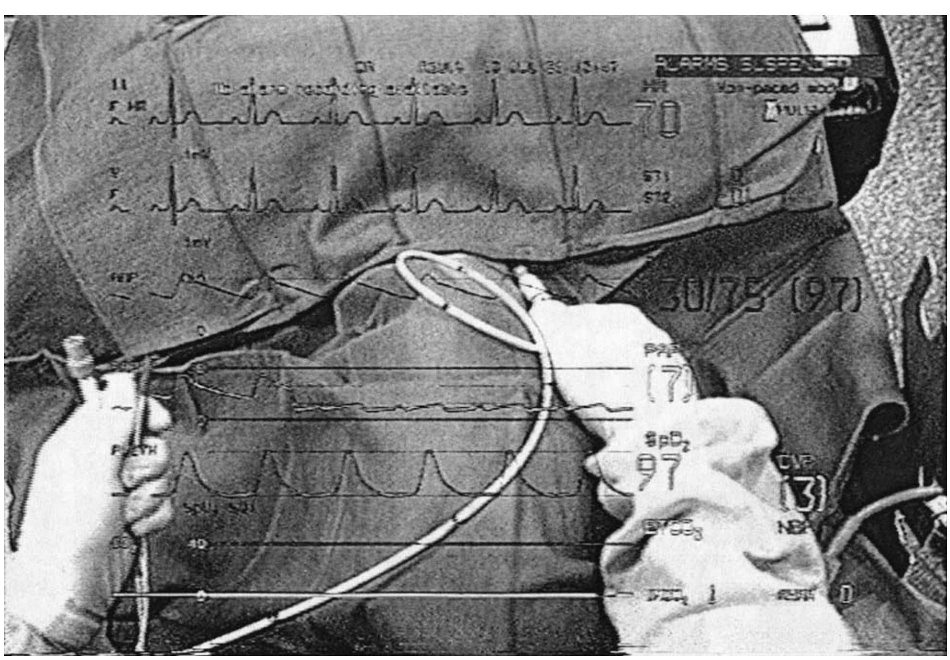

Figure 2. Example of video overlay technology projecting pulmonary artery catheter placement and wedging in the simulated OR and projected to students in the lecture hall.

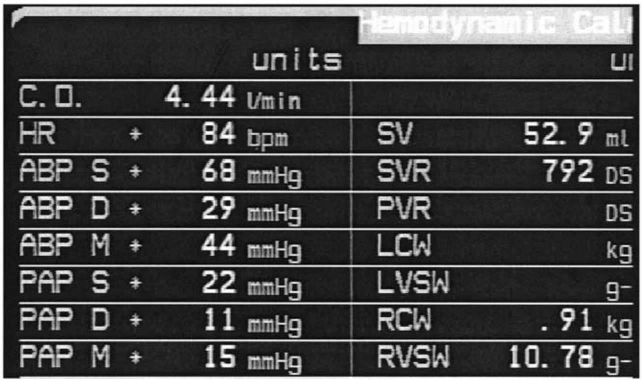

Figure 3. Clinical monitor displaying hemodynamic values for Isoflurane at 2 MAC as measured in the simulated OR. The full clinical monitor image was enlarged using the scan converter pan-zoom function to enhance clarity, and projected to students in the lecture hall.

five percent of students felt this exercise was a valuable use of their time (*Figure 4A*) and 93% felt the ADEN presentation contributed to their understanding of the pharmacology of anesthesia (*Figure 4B*). Eighty-three percent of students preferred this integrated clinically oriented review to a didactic review of the material (*Figure 4C*). Seventy eight percent of the students attending this presentation also attended the first-year hands-on small-group simulation presentation on cardiovascular physiology. Ninety two percent of those attending both the first year and this session felt the ADEN session was the same or better than the hands-on small-group simulation sessions (*Figure 4D*). All students agreed that the quality of audio and video was satisfactory (*Figure 4E and F*).

Lessons Learned and Recommendations

This study shows the feasibility of bringing a simulated clinical environment to second-year medical students *via* an ADEN and that, based on a learner satisfaction questionnaire, it is a useful teaching method from a students' perspective. In our first experience with ADEN, we report 1) the technology available to complete this teaching method, and 2) the acceptability of this method of knowledge transfer to students.

Distance education has been used in medical education to provide remote access to didactic materials (journals, texts, reading lists) and web-based examinations. There is considerable and growing demand in distance medical education[5] as technology provides ways to improve access to those individuals with busy schedules or difficulty moving to sites for educational activities. Unfortunately, most distance education tends to be noninteractive, such as materials sent *via* the postal system or retrieved from a central server. Using the Internet, high-capacity networks, and simulation technology, distance education can expand to interactive courses, or even virtual learning environments.

A limitation of previous trials has been the use of Integrated Services Digital Network (ISDN) with maximum data transfer rates of 384 and 400 Kbits/sec.[6,7] This slow data transfer rate limits the resolution of the transferred image and therefore potentially limits the kinds of images that may be sent to the distance audience. By implementing an ADEN (an Internet2 equivalent network with a 1,000 Mbits/sec backbone) we could bring an OR scenario to the students without image limitation.

The equipment used in this study was a mix of several generations and quality levels of technology. The cameras in the PSL were single chip color, with analog S-Video signal outputs. The scan converter that changed the XVGA computer-type format of the clinical monitor signal also produced an S-Video output signal. The video mixer processed these two S-Video sources into a blended S-Video output, which together with the audio signal from a microphone, was then digitized by the codec and sent over the ADEN network at the codec's maximum encoding speed, 768 Kbits/sec. Although the 768 Kbits/sec encoding is almost twice as fast as the previous distance education presentations of simulation, this situation still resulted in some limitations of resolution requiring the use of the pan/zoom function on the scan converter to

Table 3. Student Responses to the Questionnaire

Question	Answer						
	Highly Disagree	Disagree	Agree nor Disagree	Agree	Highly Agree	N/A	No Response
This exercise:							
Was a valuable use of my time	0	0	6	45	59	0	0
Contributed to my understanding the pharmacology of anesthesia	0	0	8	42	60	0	0
I prefer:							
Lecture and a small group simulation to ADEN	49	31	17	3	6	2	2
This format to a traditional lecture	1	2	16	43	48	0	0
The quality of the:							
Video was satisfactory	0	0	1	29	79	0	1
Audio was satisfactory	0	0	0	21	88	0	1

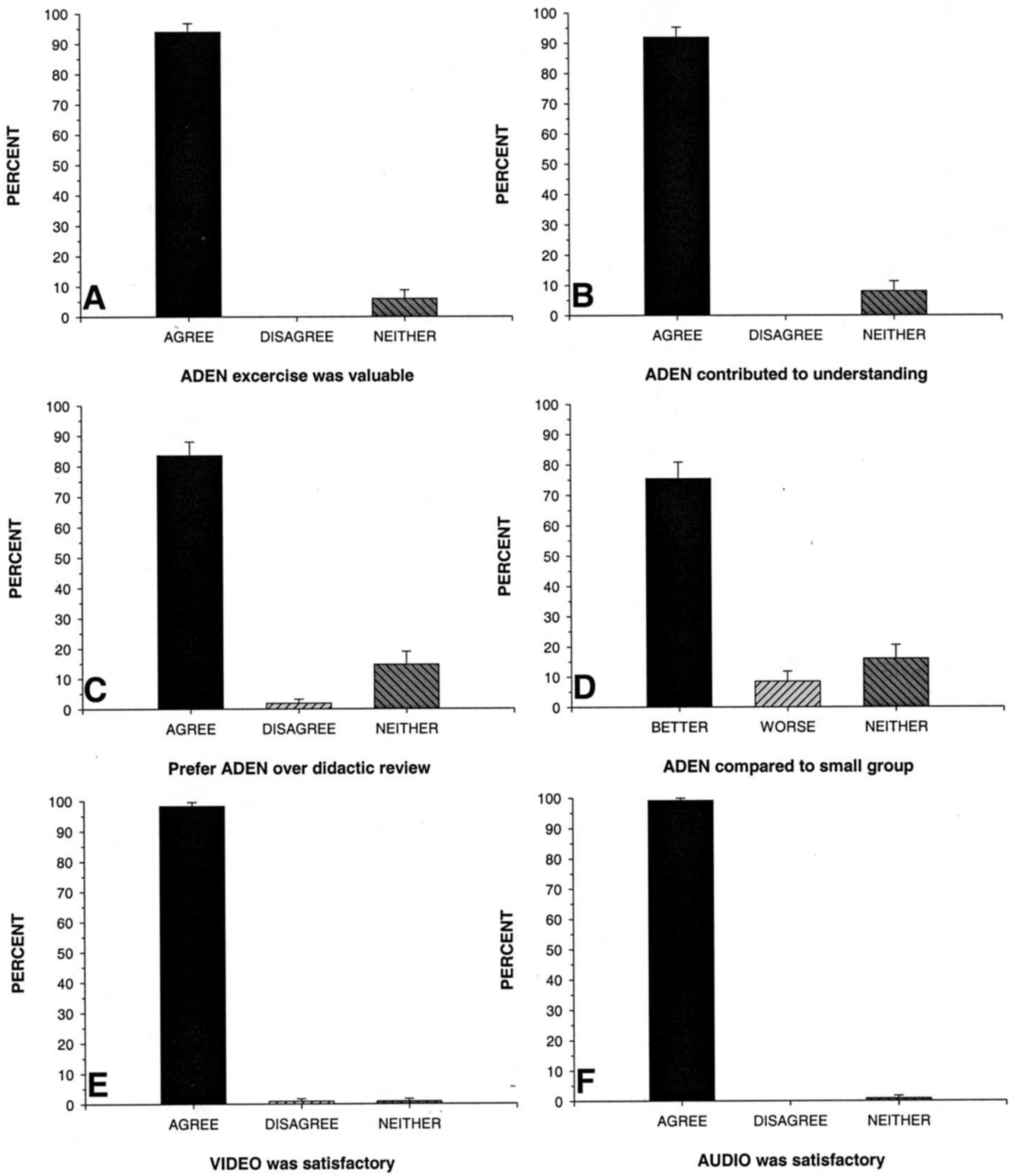

Figure 4. Composite of positive, negative, and indifferent responses with 95% confidence intervals to critical characteristics that measure the students perceived value of the ADEN presentation.

enhance the resolution and transfer of all desired information to the distant classroom.

Ideally, the video signals would have been digitized in the camera (*e.g.,* DV25 format), conveyed as digital signals (*e.g.,* IEEE-1394/FireWire format) to a digital mixer, processed, and then sent over ADEN for delivery to audio and video presentation devices that receive direct digital inputs. The required technology for an all-digital video signal distribution system is commercially available, with dramatic improvements in spatial and temporal display resolution. These upgrades would greatly facilitate the users of distance education in conveying the nuances of the clinical environment, particularly the fine detail of clinical monitors.

Although the equipment used was not of the highest fidelity possible, the students felt the technology was adequate for their learning, as evidenced by the questionnaire. Employing higher fidelity equipment may further enhance the educational process in a comparative study; however, as with all new technology, the question is when does increased cost exceed educational returns.

Student acceptance of the method of information transfer was high. The majority of students believed the ADEN-delivered simulation contributed to their understanding of the lecture material and preferred the distance education experience to lecture alone. Although manpower requirements compared to a traditional lecture are three times higher with the ADEN-enhanced lecture, the requirements are significantly less than would be required of the same laboratory in a small group format. This is based on the fact that programmatic development is the same for small group or large group teaching with simulation, and the technical personnel requirements are the same. Teaching in small-group format (typically 8 students per small group) would require 14 times as many sessions to accommodate the 110 students. In addition, students who had attended a previous course on cardiovascular physiology taught in small groups on the simulator and who also attended this session, overwhelmingly felt the distance education format was the same or better than the small groups. From an instructor's point of view, distance education lends itself to an increased ability to use clinical simulation in the basic sciences with less curriculum time disruption, while maintaining the students' perceived benefit of the experience.

The major limitation of this application of simulation and ADEN is that retention and understanding of material was not actually tested. We did not specifically measure performance improvement following the addition of simulation-based distance education compared to a control group. Unfortunately, such a study is difficult because of the perception by some students of "unequal education" if one cohort perceives to have a more effective session. This university will not allow this type of study unless a crossover occurs so that all students receive the same information by the same teaching methods in their medical education. This design would increase curriculum time requirements twofold. The early clinical exposure and high acceptance of distance education by students, including the desire for more education experiences of a similar nature, indicates that students prefer this educational process to just traditional didactic teaching methods. In addition, there is ample evidence that early clinical experience and integration of clinical with didactic medical education is advantageous,[8] and that active, rather than passive, learning is associated with better material retention.[9]

Although there still needs to be further research into the efficacy of distance education methods compared with traditional teaching methods,[10] other investigations are beginning to show the efficacy of distance education in improving performance. For example, Gul *et al.*[11] showed an 80% improvement of medical students' reporting on their videoconference experience (clarity of procedure + ability to ask questions freely + quality of time spent learning – time deemed wasted) compared to a traditional teaching method. Simulation is also beginning to show performance improvement as physicians-in-training have used simulation for improving technical skills and in the acquisition and retention of medical knowledge.[12] Standardized patients[13] and computer-based simulation[14] have also been used to improve performance in medical education. Using the Harvey Cardiovascular Patient Simulator, Ewy *et al.*[15] showed transference of skills with improved test scores on real patients. Simulation is used to improve anesthesiologists' performance in critical situations[16] through courses such as Anesthesia Crisis Resource Management.[17]

Future studies need to proceed beyond the aspects of feasibility and student satisfaction. Although at this university it is difficult to divide the students into two cohorts (one receiving the ADEN-delivered simulation session and one not) without repeating the session in a cross-over design, we could have randomized the group into two different arms (large-group simulation *via* distant education *vs.* small-group simulation). This would have allowed better analysis than the retrospective survey question of those students who had attended both simulations. This study could also have been improved by designing a pre-test and post-test that covered learning objectives of both the didactic lecture and simulated material in a design to better demonstrate the effect of the simulator on learning, and perhaps repeated during the clinical years to measure retention.

Despite limitations in design, this study did show that interactive simulation *via* an ADEN is feasible, that current limitations of data encoding can be overcome to deliver good images of clinical data, and that student acceptance of this method of knowledge transfer is high. Further work assessing education outcomes is needed.

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References

1. Matson C, Davis A, Steinkohl DC, Blavo C: How did we make the Interdisciplinary Generalist Curriculum Project work? School-level

efforts to facilitate success. *Acad Med* 2001;76(4 Suppl):S31–40.

2. Gonzales AO, Blavo C, Barley G, Steinkohl DC, Loeser H: What did we learn about early clinical experience? *Acad Med* 2001;76(4 Suppl):S49–54 , 2001.
3. O'Neill JT, Reston R, Pudimat P, Kyle R: An anesthesia patient simulator used for teaching first year medical school cardiovascular physiology [Abstract]. *FASEB J* 2001;15:A408.
4. Stoelting RK, Miller RD: *Basics Of Anesthesia, 4th ed.* Philadelphia: Churchill Livingstone, 2000:47–9.
5. Carriere MF, Harvey D: Current state of distance continuing medical education in North America. *J Contin Educ Health Prof* 2001;21:150–7.
6. Cooper JB, Barron D, Blum R, et al: Video teleconferencing with realistic simulation for medical education. *J Clin Anesth* 2000; 12(3):256–61.
7. Tooley MA, Forrest FC, Mantripp DR: MultiMed-Remote Interactive Medical Simulation. *J Telemed Telecare* 5(1 Suppl):S119–21, 1999.
8. Matson CC, Ullian JA, Boisaubin EV: Integrating early clinical experience at two medical schools: lessons learned from the Robert Wood Johnson Foundation's Generalist Physician Initiative. *Acad Med* 1999;74(1 Suppl):S53–8.
9. Schacter DL: The psychology of memory. In: Ledux J, Hirst W (eds): *Mind and Brain: Dialogues in Neuroscience.* Cambridge, UK: Cambridge University Press, 1990.
10. Mattheos N, Schittek M, Attstrom R, Lyon HC: Distance learning in academic health education. *Eur J Dent Educ* 2001;5:67–76.
11. Gul YA, Wan AC, Darzi A: Undergraduate surgical teaching utilizing telemedicine. *Med Educ* 1999;33:596–9.
12. Issenberg SB, McGaghie WC, Hart IR, et al: Simulation technology for health care professional skills training and assessment. *JAMA* 1999;282:861–6.
13. Davidson R, Duerson M, Rathe R, Pauly R, Watson RT: Using standardized patients as teachers: a concurrent controlled trial. *Acad Med* 2001;76:840–3.
14. Schwid HA, Rooke GA, Michalowski P, Ross BK: Screen-based anesthesia simulation with debriefing improves performance in a mannequin-based anesthesia simulator. *Teach Learn Med* 2001;13: 92–6.
15. Ewy GA, Felner JM, Juul D, Mayer JW, Sajid AWQ, Waugh RA: Test of a cardiology patient simulator with students in fourth-year electives. *J Med Educ* 1987;62:738–43.
16. Gaba DM: Improving anesthesiologists' performance by simulating reality. *Anesthesiology* 1992;76:491–2.
17. Howard SK, Gaba DM, Fish KJ, Yang G, Sarnquist FH: Anesthesia crisis resource management training: teaching anesthesiologists to handle critical incidents. *Aviat Space Environ Med* 1992;63:763–70.