Virtual Reality Bronchoscopy Simulation*

A Revolution in Procedural Training

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Background: **In the airline industry, training is costly and operator error must be avoided. Therefore, virtual reality (VR) is routinely used to learn manual and technical skills through simulation before pilots assume flight responsibilities. In the field of medicine, manual and technical skills must also be acquired to competently perform invasive procedures such as flexible fiberoptic bronchoscopy (FFB). Until recently, training in FFB and other endoscopic procedures has occurred on the job in real patients. We hypothesized that novice trainees using a VR skill center could rapidly acquire basic skills, and that results would compare favorably with those of senior trainees trained in the conventional manner.**

Methods: **We prospectively studied five novice bronchoscopists entering a pulmonary and critical care medicine training program. They were taught to perform inspection flexible bronchoscopy using a VR bronchoscopy skill center; dexterity, speed, and accuracy were tested using the skill center and an inanimate airway model before and after 4 h of group instruction and 4 h of individual unsupervised practice. Results were compared to those of a control group of four skilled physicians who had performed at least 200 bronchoscopies during 2 years of training. Student's *t* tests were used to compare mean scores of study and control groups for the inanimate model and VR bronchoscopy simulator. Before-training and after-training test scores were compared using paired *t* tests. For comparisons between after-training novice and skilled physician scores, unpaired two-sample *t* tests were used.**

Results: **Novices significantly improved their dexterity and accuracy in both models. They missed fewer segments after training than before training, and had fewer contacts with the bronchial wall. There was no statistically significant improvement in speed or total time spent not visualizing airway anatomy. After training, novice performance equaled or surpassed that of the skilled physicians. Novices performed more thorough examinations and missed significantly fewer segments in both the inanimate and virtual simulation models.**

Conclusion: **A short, focused course of instruction and unsupervised practice using a virtual bronchoscopy simulator enabled novice trainees to attain a level of manual and technical skill at performing diagnostic bronchoscopic inspection similar to those of colleagues with several years of experience. These skills were readily reproducible in a conventional inanimate airway-training model, suggesting they would also be translatable to direct patient care.** ***(CHEST 2001; 120:1333–1339)***

Key words: bronchoscopy training; computer simulation; medical education; virtual reality

Abbreviations: FFB = flexible fiberoptic bronchoscopy; VR = virtual reality

Virtual reality (VR) is a computer-based, simulated environment in which users interact with a high-performance computer, graphics, specialized software, and devices providing visual, tactile, and auditory feedback, thereby simulating a true-life environment. VR-simulated environments allow trainees to repeat procedural experiences at their own leisure. These exercises or procedures would otherwise require numerous real-life encounters and costly hours of supervision.[1]

A commonly recognized type of VR experience is that of flight simulation. In the aerospace, aviation, and defense industries, flight-simulation training is mandatory before pilots assume flight responsibilities. In addition, flight simulation is regularly used to help commercial airline pilots maintain their skills, or to become familiar with problems they might one day encounter.[2,3]

In the field of medicine today, simulation technology is increasingly available for learning invasive procedures.[4–8] Some might argue, therefore, that it has become unreasonable that patients be victims of medical invasive procedural training. In our experience, on-the-job training using patients can result in prolonged invasive procedures, a potential for erro-

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neous diagnoses, increased patient discomfort, and increased risk for procedure-related morbidity.

The purpose of this study was to determine whether novice physicians-in-training (pulmonary and critical care medicine trainees), using a virtual bronchoscopy skill center, could rapidly acquire basic technical skills needed to perform a common invasive diagnostic endoscopic procedure such as flexible fiberoptic bronchoscopy (FFB). We hypothesized that manual skills such as dexterity, speed, and ability to thoroughly inspect tracheobronchial anatomy, acquired in the virtual environment by novice trainees, would be applicable to flexible bronchoscopy in a conventional inanimate airway model. We also hypothesized that manual and technical skills acquired by novice trainees after limited interaction within the virtual procedural environment would compare favorably with the manual and technical skills demonstrated by more experienced senior trainees (third-year pulmonary and critical care medicine fellows from the same university training program).

MATERIALS AND METHODS

Subjects and Curriculum Design

An 8-h teaching curriculum was designed to familiarize five novice pulmonary and critical care medicine fellows during the first 3 months of their first year of training (primary study group comprised of subjects 1 to 5) with basic techniques of FFB. None were previously trained in this procedure.

The first 4 h of the curriculum included (1) a 1-h group session during which trainees observed an on-line video about FFB provided with a bronchoscopy simulator (PreOp Endoscopy Simulator; HT Medical Systems; San Jose, CA); and (2) a 1-h instructor-led overview of tracheobronchial anatomy and inspection FFB techniques, including manipulation of the flexible fiberoptic bronchoscope, operator posture, and methods of inspection of tracheal and segmental bronchial anatomy. A critical commentary of the on-line video and a demonstration of alternate techniques were also provided; and (3) a 2-h session of supervised group instruction during which each individual practiced FFB using the simulator.

The second part of the 8-h curriculum consisted of a maximum of 4 h of individual, unsupervised practice using the simulator. These practice sessions were to be completed within a 1-week period after participation in the group training session. Each trainee was assigned an individual password to log-on and use the simulator. Trainees were informed that the computer software of the simulator automatically recorded the time and duration of each log-on practice session.

Four senior, third-year pulmonary and critical care fellows with documented prior training in FFB comprised the control group (subjects 6 to 9). This group of skilled physicians had each performed > 200 FFB procedures during fellowship training at our institution. Skilled physicians were considered competent in FFB and were eligible to sit for the American Board of Internal Medicine certification examination in pulmonary medicine. Each of these physicians had previously practiced FFB using an inanimate bronchoscopy model at some point during their fellowship.

Bronchoscopy Simulator

This on-site VR skill center consists of a proxy flexible bronchoscope, a robotic interface device, and a personal computer with monitor and simulation software (PreOp Endoscopy Simulator). The proxy flexible bronchoscope is modeled after a conventional flexible fiberoptic bronchoscope, providing realistic images as the user navigates through the virtual anatomy. The robotic interface device tracks the motions of the proxy flexible bronchoscope and reproduces all forces felt during an actual bronchoscopic examination. The monitor displays computer-generated images of the airway derived from CT data sets. In addition to being anatomically correct, the virtual airway is also physiologically realistic. The virtual patient breathes, coughs, bleeds, and exhibits changes in vital signs.

The visual and functional realism of the graphic simulations of this device allows the operator to perform a thorough bronchoscopic examination of the nasopharynx, larynx, trachea, and bronchi. Virtual topical anesthetic or saline solution washes are instilled through the proxy bronchoscope, delivered using a foot pedal or mouse click. Touching the walls of the virtual airway prompts cough. A simulation of mucus on the tip of the scope can cause a white or reddish blur (red out) during which airway visualization is obscured. These events are similar to those that occur when the tip of a real bronchoscope is inadvertently wedged up against mucus or airway mucosa.

Users may choose among several virtual bronchoscopy scenarios patterned after real clinical examples. These include inspection of normal airway, endobronchial tumors, and performance of endobronchial biopsy, brushing, or BAL. For the purposes of this study, all instruction, practice sessions, and testing were limited to different scenarios of bronchoscopic inspection of normal laryngotracheobronchial anatomy only. No diagnostic procedures involving simulated accessory instruments such as forceps or brushes were used.

To perform FFB, the proxy bronchoscope is manually inserted into the simulator through the nostril of a plastic face model (Fig 1). Topical anesthetic is administered to the airways through the click of a foot pedal. During the examination, users inspect the nasopharynx, vocal cords, and tracheobronchial tree, electively identifying anatomic landmarks using a special roadmap feature (Fig 2). Users may respond to procedure-related cough or retained secretions by suctioning or changing the position of the bronchoscope within the airways. The simulator records the duration of each procedure, the amount of topical anesthetic used, the number and sequence of bronchial segments inspected, the number of collisions with the tracheobronchial wall, and the duration of red out (defined as time during which airway anatomy cannot be visualized because of improper positioning of the bronchoscope due to overwedging, wall collision, or loss of direction).

Inanimate Bronchoscopy Model

This well-known model of the head and chest (Laerdal Airway Management Trainer; Laerdal; Stavanger, Norway) includes a plastic larynx and tracheobronchial tree that allows users to thoroughly inspect upper and lower airway structures (Fig 3). Bronchoscopy is performed through either the nose or the mouth. During bronchoscopy, the operator cannot see the model tracheobronchial tree inside the chest. A hinged panel on the anterior chest wall can be removed, however, providing access to the model airway and observation of the procedure "from the outside."

FFB in the inanimate model was performed using a videobronchoscope (Olympus BFP 200; Olympus; Long Beach, CA). Procedures were recorded and witnessed by the investigators

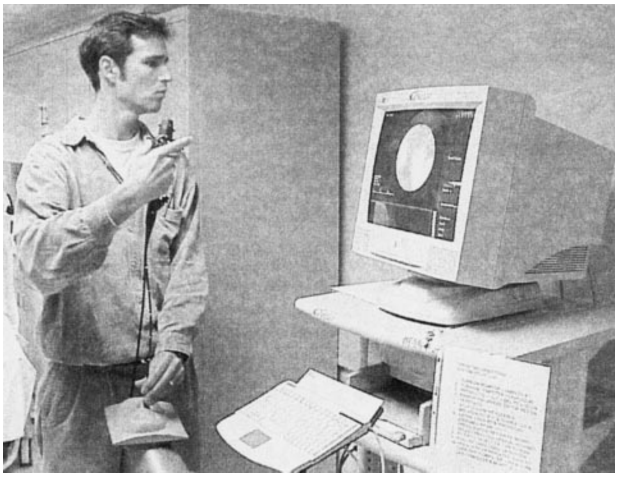


FIGURE 1. The VR bronchoscopy skill station includes a cart, computer, display, printer, proxy flexible bronchoscope, and keyboard. While the operator performs FFB via the left nares, realistic resistance is felt during manipulation of the proxy flexible bronchoscope.

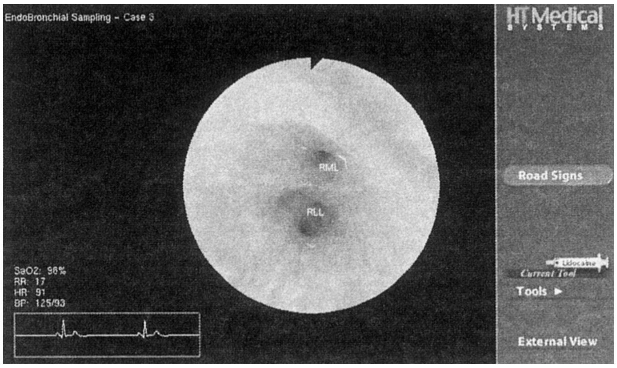
FIGURE 3. Using an inanimate bronchoscopy model, the operator performs videobronchoscopy through the left nares while images of segmental tracheobronchial anatomy are viewed on screen. The distal extremity of the videobronchoscope is easily visible within the plastic tracheobronchial tree when the hinged front piece on the inanimate model is raised.

(H.G.C. and S.W.C.), who monitored the procedure by viewing the video screen and watching segmental bronchial inspection through the raised panel in the anterior chest wall of the model.

Study Protocol

Study Group Pretraining Performance Testing: After the didactic group instruction session, novice trainees performed a bronchoscopic inspection of normal laryngotracheobronchial anatomy using first the simulator and then the inanimate model. Because the novice trainees had no prior exposure to the inanimate model, trainees were each allowed 10 min to familiarize themselves with the videobronchoscope and the inanimate model prior to testing. Trainees were instructed to perform a thorough procedure as if they were looking for a source of bleeding in a patient with hemoptysis. Immediately prior to testing, novice trainees were each allowed to perform one complete practice bronchoscopic examination on the simulator and in the inanimate model.

Study Group Posttraining Performance Testing: After completing a maximum of 4 h of unsupervised, individual practice on the bronchoscopy simulator, novice trainees were again tested on the simulator using a previously unobserved scenario of normal laryngotracheobronchial anatomy. Novice trainees were then tested on the inanimate model. None of the trainees had been allowed to practice on the inanimate model during the previous week. Instructions and investigator observations during the posttraining measurement sessions were identical to those used for pretraining testing. Each student was again allowed to perform one complete practice FFB on the simulator and the inanimate model prior to testing.



EndoBronchial Sampling – Case 3

SaO2: 96%
RR: 17
HR: 91
BP: 125/93

FIGURE 2. Segmental tracheobronchial anatomy appears textured and realistic on screen, similar to images seen during videobronchoscopy examinations. A roadmap features labels segmental anatomy if needed.

Control Group: After a 30-min session of supervised practice using the bronchoscopy simulator, skilled physicians were tested on the simulator and then on the inanimate model, using a protocol identical to that used for novice trainees. Although each skilled physician had prior experience using a videobronchoscope and the inanimate model during fellowship training, an additional 10 min was allowed so that they could further familiarize themselves with both prior to testing.

Outcome Measures

Using the VR bronchoscopy simulator, a computer-generated record identified elements of manual skill which we defined as (1) *dexterity*, the number of contacts with the tracheobronchial wall per minute of FFB, and the number of minutes in red out per minute of FFB; (2) *accuracy*, the thoroughness of examination as measured by number of bronchial segments missed; and (3) *speed*, the duration of FFB from start to finish. In the inanimate model, speed (duration) and accuracy (number of bronchial segments missed) were measured by having one investigator view the procedure on the video screen, while the other investigator counted the number of bronchial segments entered by viewing the procedure through the raised, hinged panel on the anterior chest wall of the model. All procedures in the inanimate model were videotaped for off-line review by the investigators to ensure accuracy.

Statistical Analysis

Student's t tests were used to compare mean scores of study and control groups of each category for both the inanimate model and VR bronchoscopy simulator. Pretraining and posttraining test score comparisons were made using paired *t* tests. For comparisons between posttraining novice trainee and skilled physician scores, unpaired two sample *t* tests were used. Differences were considered statistically significant at $p < 0.05$.

Results

All novice trainees completed their individual, unsupervised training curriculums using the simulator. Four study subjects trained for the full 240 min allowed, whereas one subject trained for 210 min. The average duration of each individual practice session was 78 min (range, 30 to 160 min). Prior to this study, novice trainees had had only minimal exposure to FFB, having each previously observed or participated in an average of 10 procedures during their medical training (range, 0 to 15 procedures).

Novice trainees significantly improved their dexterity and accuracy in both models (Tables 1, 2). They missed fewer segments after training than before training, and had fewer contacts with the bronchial wall. These improvements were not accompanied, however, by a statistically significant improvement in speed (Tables 1, 2). The total time spent not visualizing airway anatomy (because of red out) was unchanged.

There were no statistically significant differences between novice scores after training and skilled physician scores. In addition, novices posttraining performed more thorough examinations, missing significantly fewer segments than skilled physicians in both the inanimate and virtual simulation models (Tables 3, 4). A trend toward improved speed, less contacts with the bronchial wall per minute of bronchoscopy, and less time spent in red out was noted, however, in the group of skilled physicians.

Discussion

FFB is a commonly performed endoscopic procedure used for diagnosis and treatment of a variety of airway and pulmonary disorders. More than 500,000 of these procedures are performed each year by pulmonologists, otolaryngologists, anesthesiologists, and thoracic surgeons.[9] Presumed competence in FFB is traditionally achieved during postgraduate specialty training. For pulmonologists, this entails 2 to 3 years of fellowship training after internal medicine residency.[10]

During fellowship training, novice bronchoscopists learn to manipulate the flexible fiberoptic or video bronchoscope (prices for these fragile instruments range from \$16,000 to \$20,000) by initially watching their attending faculty perform a procedure, and then by performing examinations themselves under faculty supervision. Manual and technical skills are gradually acquired along with decision-making and interpretation skills through a combination of one-on-one interactions, patient-care experiences, and didactic lectures held at national conferences.

Despite the widespread practice of diagnostic flexible bronchoscopy, there are no firm guidelines that assure a uniform acquisition of basic skills and competency in this procedure nationwide, nor are there guidelines to ensure uniform training and competency in advanced diagnostic flexible bronchoscopic techniques, such as transbronchial needle aspiration biopsy or fluorescence bronchoscopy. In a recent study[11] sponsored by the American Association for Bronchology, 87% of pulmonologists surveyed believed that > 50 basic FFB procedures were necessary to become competent in this procedure, a significant increase from the 61% of pulmonologists that believed this 10 years ago.[12] In addition, $> 50\%$ of respondents stated that their instruction in a newer diagnostic bronchoscopic procedure, such as transbronchial needle aspiration, had been insufficient during their training.

Haponik et al[13] recently reported the perspective of senior pulmonary trainees regarding their bronchoscopy training. Most trainees had high estimations of their experience, although significant variability in training was noted. High self-estimates of proficiency were most associated with one-on-one

Table 1—*Results for Novice Trainees (n = 5) Using VR Bronchoscopy Simulator Before and After VR Training**

Outcome Measures	Pre-VR Training	Post-VR Training	p Value
Speed (duration of bronchoscopy), min:s	10:20 (7:14–14:52)	10:16 (6:46–14:56)	0.487
Dexterity (contacts with bronchial wall per minute of bronchoscopy), No.	13:8 (10:1–17.0)	11.4 (7.5–14.8)	0.022†
Time in red out, %	34 (24–49)	26 (9–42)	0.183
Accuracy (segments missed), No.	4.4 (2–7)	0.8 (0–3)	0.029†
Percent of total	25 (39–12)	4.5 (0–17)	

*Data are presented as mean (range).

†Significant at $p < 0.05$.

Table 2—*Results for Novice Trainees (n = 5) Using Inanimate Model Before and After VR Training**

Outcome Measures	Pre-VR Training	Post-VR Training	p Value
Speed (duration of bronchoscopy), min:s	6:47 (4:10–9:10)	5:47 (3:51–8:01)	0.204
Accuracy (segments missed), No.	2.8 (1–5)	0	0.007†
Percent of total	17 (28–06)	0	

*Data are presented as mean (range).

†Significance at $p < 0.05$.

training. The authors believe that "an effort to appraise and enhance the quality of bronchoscopy training is necessary." This need to "improve training efforts to attain goals of graduate competence and patient safety" was reiterated in an accompanying editorial[14] appealing to pulmonary and critical care medicine fellowship training program directors.

Achieving competence in an invasive medical procedure such as bronchoscopy, however, first requires operators to acquire manual and technical skills such as dexterity, thoroughness of examination techniques, and an ability to work quickly and gently; procedures are performed in fully awake patients or using light conscious sedation. Ideally, bronchoscopists should also master protocols that ensure patient, instrument, and operator safety, as well as gain cognitive knowledge and decision-making skills.

Traditionally, manual and technical skills are acquired over time as bronchoscopists perform more and more procedures. These skills may be learned on the job, but also in the animal laboratory or by using inanimate plastic models such as the airway model used in this study. These methods of learning, however, do not provide students with constructive criticism or opportunities to repeat and correct faulty maneuvers unless an instructor is present, one-on-one, to assess performance and demonstrate proper and improper procedure-related techniques. In addition, the rigid construction of most inanimate models risks damaging fragile and expensive instruments such as a flexible fiberoptic bronchoscope or videobronchoscope. More importantly, the simulation of real-life events such as respiratory movements, vocal cord closure, obstructing airway secretions, cough, or procedure-related hemodynamic compromise and other adverse events are impossible in the animal and inanimate model settings.

The virtual environment has none of the above disadvantages. In fact, the results of our study, despite the small numbers of subjects, show that a short, focused course of instruction and unsupervised practice using a virtual bronchoscopy simulator enabled novice trainees to attain a level of basic manual and technical skill at performing a thorough diagnostic bronchoscopic inspection of the tracheobronchial tree. Moreover, novice trainees acquired manual skills using the virtual bronchoscopy simulator that were similar to those of colleagues with several years of clinical bronchoscopic experience. The skills acquired in the virtual environment were not limited to that environment, being readily reproducible in a conventional inanimate airway-training model. The fact that simulation-based training improved bronchoscopy skills in the inanimate model suggests that it would also improve performance in direct patient care.

These findings reinforce results recently published in abstract form, in which other investigators note that this bronchoscopy simulator could distinguish levels of clinical experience among beginners and experienced bronchoscopists.[15,16] The duration of bronchoscopy, time in red out, and collisions with airway walls for experienced and inexperienced

Table 3—*Results Using VR Bronchoscopy Simulator for Novices After VR Training (n = 5) Compared With Those of Skilled Physicians (n = 4)**

Outcome Measures	Novice Trainees Post-VR Training	Skilled Physicians	p Value
Speed (duration of bronchoscopy), min:s	10:16 (6:46–14:56)	7:01 (6:58–7:55)	0.062
Dexterity (contacts with bronchial wall per minute of FFB), No.	11.4 (7.5–14.8)	9.8 (8.1–12.1)	0.18
Time in red out, %	26 (9–42)	24 (10–34)	0.43
Accuracy (segments missed), No.	0.8 (0–3)	5.25 (3–8)	0.009†
Percent of total	4.5 (0–17)	29 (17–45)	

*Data are presented as mean (range).

†Significance at $p < 0.05$.

Table 4—*Results Using the Inanimate Model for Novices After VR Training (n = 5) Compared With Those of Skilled Physicians (n = 4)**

Outcome Measures	Novice Trainees Post-VR Training	Skilled Physicians	p Value
Speed (duration of bronchoscopy), min:s	5:47 (3:51–8:01)	5:11 (3:45–7:15)	0.33
Accuracy (segments missed), No.	None	3.25 (1–7)	0.045†
Percent of total	0	17 (5–38)	

*Data are presented as mean (range).

†Significance at $p < 0.05$.

trainees were similar between those studies and the present report. More than correlating levels of experience, however, our study clearly demonstrates that technical and manual skills, such as thoroughness of examination, dexterity, and speed, can be rapidly acquired in an environment based on computer simulation.

In medical and surgical specialties such as cardiology, laparoscopic surgery, and anesthesiology, simulation technology is already being advocated for skills training or competency assessments.[17–20] Using devices such as the Eagle (CEA Electronics; Binghamton, NY) or the McGill Inanimate System for Training and Evaluation of Laparoscopic Skills (Montreal, Canada), students have been shown to improve technical as well as clinical skills.[1] Work is ongoing to determine whether training on a simulator improves knowledge acquisition and retention in comparison to traditional learning techniques.

The results of our study support our belief that the incorporation of simulation technology for training bronchoscopists will engender a revolution in pulmonary procedural training. Instead of using the orthodox system of developing competence by seeing, doing, and teaching procedures on real patients, skills can be readily acquired using virtual simulation. In this environment, bronchoscopy training readily includes deliberate action, reaction, opportunities for repetition, correction of errors, and ability for individualized learning, all key components of the educational process. Time-consuming instructor presence is usually unnecessary during training sessions, as trainees can select among diverse scenarios in order to repeat and practice procedures at their leisure. Feedback on their performance can be obtained from computer-generated reports or video review, substantially enhancing supplemental learning from one-on-one interactions with an expert instructor.

Learning through simulation, therefore, addresses the concerns raised by Haponik et al[13] and provides a means to simultaneously appraise and enhance the uniform quality of bronchoscopy training. This technology will not only dramatically change training strategies for endoscopists, but will ultimately be adopted in medical procedural competency assessments, analogous to flight simulation for commercial airline pilots.

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References

1 Issenberg SB, McGeghie WC, Hart IR, et al. Simulation technology for health care professional skills training and assessment. JAMA 1999; 282:861–867

2 Rolfe JM, Staples KJ. Flight simulation. Cambridge, UK: Cambridge University Press, 1986; 232–249

3 Ressler EK, Armstrong JE, Forsythe GB. Military mission rehearsal. In: Tekian A, McGuire C, McGaghie WC, eds. Innovative simulations for assessing professional competence. Chicago, IL: Department of Medical Education, University of Illinois Medical Center, 1999; 157–174

4 Satava RM, Jones SB. Virtual reality. In: Satava RM, ed. Cybersurgery, advanced technologies for surgical practice. New York, NY: Wiley-Liss, 1998; 75–95

5 Ursino M, Tasto JL, Nguyen BH, et al. CathSim: the first low-cost intravascular catheterization simulator on a PC. In: Proceedings of Medicine Meets Virtual Reality 7; San Francisco, CA; January 20–23, 1999; 360–366

6 Psotka J. Immersive training systems: virtual reality and education and training. Instructional Sci 1995; 23:405–431

7 Bro-Nielsen M, Tasto JL, Cunnigham RL, et al. PreOp endoscopic simulator: a PC-based immersive training system for bronchoscopy. In: Proceedings of Medicine Meets Virtual Reality 7; San Francisco, CA; January 20–23, 1999; 76–82

8 Derossis AM, Fried GM, Abrahamowicz M, et al. Development of a model for training and evaluation of laparoscopic skills. Am J Surg 1998; 175:482–487

9 Centers for Disease Control and Prevention. Vital and health statistics: ambulatory and inpatient procedures in the United States, 1996. Hyattsville, MD: US Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Health Statistics, 1998; DHHS publication 99–1710

10 Committee on Bronchoesophagology. Standards for training in endoscopy. Chest 1976; 69:665–666

11 Colt HG, Prakash UBS, Offord KP. Bronchoscopy in North America; survey by the American Association for Bronchology, 1999. J Bronchol 2000; 7:8–25

12 Prakash UBS, Offord KP, Stubbs SE. Bronchoscopy in North America: the ACCP survey. Chest 1991; 100:1668–1675

13 Haponik EF, Russell GB, Beamis JF, et al. Bronchoscopy

training: current fellows' experiences and some concerns for the future. Chest 2000; 118:625–630

14 Torrington KG. Bronchoscopy training and competency: how many are enough [editorial]. Chest 2000; 118:572–573

15 Britt EJ, Tasto JL, Merril GL. Assessing competence in bronchoscopy by use of a virtual reality simulator. In: Proceedings of the Jubilee 10th World Congress for Bronchology and 10th World Congress for Bronchoesophagology. Budapest, Hungary; June 14–17, 1998; 10

16 Mehta AC, Ost D, Salinas SG, et al. Objective assessment of bronchoscopy skills by a bronchoscopy training simulator [abstract]. Am J Respir Crit Care Med 2000; 161:A234

17 Gordon MS, Ewy GA, Felner JM, et al. Teaching bedside cardiologic examination skills using "Harvey" the cardiology patient simulator. Med Clin North Am 1980; 64:305–313

18 Derossis AM, Bothwell J, Sigman HH, et al. The effect of practice on performance in a laparoscopic simulator. Surg Endosc 1998; 12:1117–1120

19 Abrahamson S, Denson JS, Wolf RM. Effectiveness of a simulator in training anesthesiology residents. J Med Educ 1969; 44:515–519

20 DeAnda A, Gaba DM. Role of experience in the response to simulated critical incidents. Anesth Analg 1990; 71:77–82