Validation of a Computer-based Bronchoscopy Simulator Developed in Taiwan

Jin-Shing Chen, Hsao-Hsun Hsu, I-Ru Lai, Hao-Chih Tai, Hong-Shiee Lai, Yung-Chie Lee, Jin-Siang Shaw,1 Yi-Ping Hung,2 Po-Huang Lee, King-Jen Chang,* for the National Taiwan University Endoscopic Simulation Collaborative Study Group (NTUESC)†

Background/Purpose: Conventional training in bronchoscopy may increase patient’s discomfort and procedure-related morbidity. Computer-based bronchoscopy simulator (CBBS) permits the acquisition and evaluation of the necessary skills through a realistic bronchoscopic experience. This study was conducted to validate the use of a CBBS system developed in Taiwan as a learning and assessment tool.

Methods: Twenty novice bronchoscopists and 10 expert bronchoscopists were enrolled as subjects in this prospective study. The 20 novice bronchoscopists were randomized into two groups, which received conventional bronchoscopic training or CBBS training and then completed a satisfaction survey. Subsequently, the novices who received CBBS training underwent an observational performance trial and the results were compared with those of expert bronchoscopists. All 10 expert bronchoscopists completed a realism survey and observational trial after CBBS performance.

Results: The satisfaction survey showed that the CBBS training program significantly increased participants’ satisfaction (p = 0.002) and interest in learning (p < 0.001). The realism survey by the 10 expert bronchoscopists indicated that CBBS provides a favorable degree of realism with regard to the mechanical and visual parameters examined. Analysis of the performance results showed that the following parameters were capable of differentiating the participants by level of expertise: total procedure time (p = 0.002), percentage of bronchial segments entered (p = 0.012), percentage of bronchial segments identified (p < 0.001), percentage of repeated bronchial segments entered (p = 0.004), percentage of pathologies identified (p < 0.001), number of times that the bronchoscope tip collided with airway walls (p = 0.013), and number of times oral instruction was needed (p = 0.01).

Conclusion: CBBS is a valid training method that increases interest in learning and provides a favorable degree of virtual realism. It can also distinguish various levels of competence at actual bronchoscopy and may have a useful role in the bronchoscopic training curriculum. [J Formos Med Assoc 2006;105(7):569–576]

Key Words: bronchoscopy, computer, simulation, training

Flexible bronchoscopy is a commonly performed endoscopic procedure for diagnosis and treatment of a variety of airway and pulmonary disorders. Despite its widespread practice, there are no firm training guidelines that ensure a uniform acquisition of basic skills and competency in this procedure.1,2 Conventional training involves a trainee performing bronchoscopy on a real patient

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Department of Surgery, National Taiwan University Hospital and National Taiwan University College of Medicine, †Department of Mechanical Engineering, National Taipei University of Technology, and 2Graduate Institute of Networking and Multimedia, National Taiwan University, Taipei, Taiwan.

†A complete list of NTUESC members and their affiliations appears in the Acknowledgments.

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*Correspondence to: Dr King-Jen Chang, Department of Surgery, National Taiwan University Hospital and National Taiwan University College of Medicine, 7, Chung-Shan South Road, Taipei 100, Taiwan. E-mail: kingjen@ha.mc.ntu.edu.tw
under supervision. This method of training is not only expensive, but also increases the potential for patient discomfort, procedure-related morbidity, and risk of erroneous diagnoses. Simulators permit the acquisition of the necessary technical skills while avoiding these problems, and thus play an important role in learning invasive procedures.

Several training simulation models have been developed to introduce trainees to bronchoscopic procedures. Among them, computer-based bronchoscopy simulators (CBBSs) are intended to provide a realistic bronchoscopic experience and feedback to operators regarding procedure skills. Additionally, these systems may eventually serve as an adjunct objective measure of competence. Before CBBS can take on a role in training and the evaluation of training, it must be shown to adequately reproduce actual bronchoscopies in patients and to record meaningful performance data.

Some commercially available CBBSs have demonstrated promising results for providing a reliable learning and assessment tool and differentiating participants by varying levels of experience. However, all of these computer-based simulators are made in Europe or North America, and their prices are very high, ranging between 50,000 and 100,000 US dollars. In addition, the difficulty of maintaining and the impossibility of upgrading many of these systems make them unsuitable or unaffordable for most medical education systems in developing countries such as Taiwan. With the support of the National Science Council, the National Taiwan University Endoscopic Simulation Collaborative Study Group (NTUESC) began, in 2000, to develop various flexible endoscopic simulation systems, including systems for bronchoscopy, esophagogastroduodenoscopy, and colonoscopy. The prototype of the CBBS was completed in 2004 and is now ready for commercialization. The estimated price is around US$25,000.

The purposes of this study were to determine if the CBBS prototype developed by the NTUESC can provide a realistic experience, and if CBBS performance parameters can differentiate between varying levels of bronchoscopic experience.

**Methods**

**Description of the simulator**
The NTUESC CBBS (National Taiwan University, Taipei, Taiwan) consists of a proxy flexible
bronchoscope, a robotic mannequin, a computer with monitor, and simulation software (Figure 1A). These components combine to create a realistic and immersive training environment for learning and practicing flexible bronchoscopy.

As shown in Figure 1B, when the proxy bronchoscope is physically inserted into the mouth of the mannequin, it triggers the software program in the main control computer, which brings up sequential computer-generated images of the tracheobronchial trees. The three-dimensional (3D) computer-generated model of the tracheobronchial trees was constructed using radiographic data sets from actual patients, including digital axial anatomic images at 1.0 mm intervals with associated computed tomography (CT) and magnetic resonance imaging (MRI) images. Texture maps based on videotapes of actual bronchoscopic images were added to give the mucosa of the virtual airway a realistic look. The 3D controller (proxy bronchoscope) is designed to mimic the appearance, feel, and method of operation of an actual bronchoscope. The monitor displays computer-generated images of the airway as the user navigates through the virtual anatomy. Figure 2A shows an example of the virtual anatomy at the level of the right upper lobe takeoff.

In addition to being anatomically correct, the virtual patient also behaves in a physiologically realistic manner. The patient breathes, coughs, and exhibits changes in vital signs if an inappropriate action is taken. Collision occurs when the distance between the proxy bronchoscope tip and the tracheobronchial wall is less than a given value. Collision with the tracheobronchial wall will result in a simulated patient cough and obscure the field of view of the bronchoscope, which means that the user must instill lidocaine to clear the field of view. However, frequent instillation of lidocaine will cause the patient to develop cardiac arrhythmia and hypoxemia, and finally the examination will not be completed after reaching a preset accumulative dose of lidocaine.

The CBBS system includes three different virtual patient cases of increasing difficulty. In addition to normal health status, the system also provides various pathologies, including tumor, hemorrhage, stenosis, and sputum impaction, in different anatomical locations, allowing a wide range of training scenarios. To prevent the inexperienced novice bronchoscopist from getting lost during the procedure, the system also provides an external view to help the user visualize the location of the scope (Figure 2B). Snapshots can also be taken for identified pathologies.

The simulation software records all the actions of the user, including time taken for the procedure, percentage of bronchial segments entered, percentage of pathologies identified, number of times that the bronchoscope tip

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**Figure 2.** (A) Bronchoscopic view of the simulated airway at the level of the right upper lobe takeoff; a, the main bronchoscopic view; b, snapshots taken from areas of interest; c, vital signs of the patient; d, records of the user. (B) External view of the CBBS allows users to visualize the location of the scope.
collides with airway walls, and the amount of lidocaine used.

The software runs on a personal computer with a 1.4 GHz Intel Pentium IV processor and Microsoft Windows XP. The computer also requires a graphics acceleration card.

**Study design and subjects**

Figure 3 shows the algorithm for validation of the CBBS. The study subjects consisted of 20 novice bronchoscopists and 10 expert bronchoscopists. Novice bronchoscopists were defined as being familiar with the anatomy of the tracheobronchial tree but have never performed a bronchoscopy. Expert bronchoscopists were defined as attending pulmonary physicians who had performed more than 300 flexible bronchoscopic examinations. The 20 novice bronchoscopists were randomized into two groups (10 in each group) to receive conventional bronchoscopic training (conventional group) or CBBS training (CBBS group). Conventional bronchoscopic training consists of watching videotapes and observing actual bronchoscopy procedures. CBBS training consists of CBBS practice and observation of actual bronchoscopy procedures. After completion of training, all novice bronchoscopists completed a satisfaction survey about the teaching materials. Subsequently, novices in the CBBS group underwent an observational trial and their results were compared with those of expert bronchoscopists. All 10 expert bronchoscopists completed a realism survey and observational trial after CBBS performance.

**Validation by survey questionnaire**

After completion of the conventional or CBBS training, the 20 novice bronchoscopists completed a four-question survey to assess agreement with the propositions that the offered training materials can increase knowledge of tracheobronchial anatomy, knowledge of tracheobronchial pathologies, satisfaction with training materials, and interest in learning how to perform bronchoscopy. The agreement was rated with a five-point Likert scale (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree).

The 10 expert bronchoscopists also completed a six-question survey in which the visual and mechanical realism of the simulation system was rated with a 10-point Likert scale (1 = very unrealistic, 5 = neutral, 10 = very realistic). The factors assessed were the realism of the visual graphics, spatial and anatomical relationships, the force required during insertion and the tactile feel of resistance, the response of the visualized lumen to manipulation of the control knobs, status of various pathologies identified and, finally, overall satisfaction with the system.

**Validation by observational trial**

To determine whether this bronchoscopy simulator would be able to distinguish between novices

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**Figure 3. Algorithm for validation of the CBBS.**
and experts on the basis of various measures of bronchoscopy performance, 10 expert bronchoscopists and 10 novice bronchoscopists were enrolled. After a brief introduction and demonstration of the CBBS using a standardized protocol, each participant practiced on the CBBS for at least 10 minutes. Then they performed examinations on two standard simulated cases, and performance parameters were recorded. The first case was a patient with normal tracheobronchial findings, and the second patient presented with 5–10 endobronchial pathologies. The performance parameters included total procedure time, percentage of bronchial segments visualized, percentage of bronchial segments identified, percentage of repeated bronchial segments entered, percentage of pathologies identified, wall collisions, and total amount of lidocaine used. Total procedure time was measured from the moment of scope insertion to the level of the vocal cords of the robotic mannequin to the moment of scope removal from the same location. The simulator also simultaneously measured the percentage of bronchial segments visualized. A bronchial segment was classified as visualized during the procedure if the virtual bronchoscope passed beyond a certain point in the bronchial tree. A given bronchial segment was classified as identified if the participant could visualize and name it correctly. Finally, oral instruction was given when participants had difficulties during the procedure that could not be fixed within 30 seconds. For example, when participants became lost during the procedure or could not manipulate the virtual bronchoscope appropriately into a specific segmental bronchus. If oral instruction did not solve the problem, physical instruction was provided by taking over the bronchoscope and demonstrating the appropriate technique to the participants. The number of times of oral or physical instruction was also recorded.

**Data analyses**

Differences in responses to the satisfaction survey of training materials between novice bronchoscopists in the conventional and CBBS groups were analyzed by nonparametric Mann–Whitney U test. Differences in performance parameters for cases 1 and 2 on the simulator between novice and expert bronchoscopists were analyzed by unpaired two-sample t tests. SPSS 10.0 statistical software was used to analyze the data, and differences were considered statistically significant at \( p < 0.05 \).

**Results**

The satisfaction survey of training materials in 20 novice bronchoscopists showed that, compared with the conventional bronchoscopic training method, the CBBS training program significantly increased participants’ satisfaction and increased interest in learning (Table 1). The survey also showed a trend that the CBBS program increased knowledge of tracheobronchial anatomy compared to conventional bronchoscopic training materials, although this difference was not significant (\( p = 0.075 \)). The average scores for all the four questions in the CBBS group were >4, indicating that most novice bronchoscopists were satisfied or very satisfied with the CBBS teaching system.

The survey scores from 10 expert bronchoscopists demonstrated that CBBS provides a favorable

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**Table 1.** Comparison of satisfaction with training materials between novice bronchoscopists in the conventional and CBBS groups*

|                          | Conventional group \( (n = 10) \) | CBBS group \( (n = 10) \) | \( p \)
|--------------------------|-----------------------------------|---------------------------|-------
| Can increase knowledge of anatomy | 3.3 (3–5)                       | 4.1 (3–5)                 | 0.075 |
| Can increase knowledge of pathologies | 3.6 (3–5)                       | 4.0 (3–5)                 | 0.247 |
| Can increase satisfaction with teaching materials | 3.2 (2–4)                       | 4.5 (3–5)                 | 0.002 |
| Can increase interest in learning | 2.6 (2–4)                       | 4.5 (4–5)                 | <0.001 |

*Scores are based on a five-point scale (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree) and are expressed as mean (range); \(^{1}\)analyzed by nonparametric Mann–Whitney U test. CBBS = computer-based bronchoscopy simulator.
Figure 4. CBBS realism survey of 10 expert bronchoscopists. Average realism scores are shown with 95% confidence intervals. Scores are based on a 10-point scale (1 = very unrealistic, 5 = neutral, 10 = very realistic).

Table 2. Performance results for cases 1 and 2 on the simulator for novice and expert bronchoscopists*

<table>
<thead>
<tr>
<th>Bronchoscopy experience level</th>
<th>Novice (n = 10)</th>
<th>Expert (n = 10)</th>
<th>p^1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total procedure time (s)</td>
<td>707 ± 190</td>
<td>450 ± 88</td>
<td>0.002</td>
</tr>
<tr>
<td>Segments entered (%)</td>
<td>91 ± 9</td>
<td>100 ± 0</td>
<td>0.012</td>
</tr>
<tr>
<td>Segments identified (%)</td>
<td>35 ± 19</td>
<td>95 ± 16</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Segments repeated (%)</td>
<td>9 ± 7</td>
<td>1 ± 2</td>
<td>0.004</td>
</tr>
<tr>
<td>Pathologies identified (%)</td>
<td>81 ± 7</td>
<td>97 ± 5</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Scope collisions (n)</td>
<td>7.0 ± 2.4</td>
<td>4.5 ± 1.4</td>
<td>0.013</td>
</tr>
<tr>
<td>Lidocaine usage (mg)</td>
<td>8.1 ± 2.7</td>
<td>6.6 ± 2.4</td>
<td>0.216</td>
</tr>
<tr>
<td>Times of oral instruction (n)</td>
<td>1.5 ± 0.7</td>
<td>0.6 ± 0.7</td>
<td>0.01</td>
</tr>
<tr>
<td>Times of physical instruction (n)</td>
<td>0.7 ± 0.7</td>
<td>0.3 ± 0.5</td>
<td>0.147</td>
</tr>
</tbody>
</table>

*Values expressed as mean ± standard deviation; ^1 analyzed by the unpaired two-sample t test.

degree of realism with regard to the mechanical and visual parameters that were examined (Figure 4). The realism of the bronchoscopic spatial relationship received the highest score of 7.4 (95% confidence interval, CI, 6.9, 7.9) on the 10-point Likert scale. Overall satisfaction with the system was also favorable, with a score of 7.0 (95% CI, 6.6, 7.4). Simulation of pathologies achieved the lowest score of 5.4 (95% CI, 4.9, 5.9), indicating a lack of realism and need for further modification.

Analysis of the performance results demonstrated that the following parameters were capable of differentiating the participating subjects by level of expertise: total procedure time, percentage of bronchial segments entered, percentage of bronchial segments identified, percentage of repeated bronchial segments entered, percentage of pathologies identified, number of times the bronchoscope tip collided with airway walls, and number of times that oral instruction was needed (Table 2). Among them, the most significant difference came from the percentage of bronchial segments identified. Expert bronchoscopists identified nearly every segment promptly and correctly (95%). On the other hand, novice bronchoscopists only identified the initial several segments that they entered (35%), and got lost thereafter. The total dose of lidocaine used and the number of times that physical instruction was required were comparable between the two groups.

Discussion

This study demonstrated the validity and potential utility of the first CBBS developed in Taiwan. Assessment of the CBBS by a satisfaction survey among novice bronchoscopists, a realism survey among expert bronchoscopists, and its ability to distinguish expert from novice bronchoscopists, indicated that the system provides a valid and accurate reproduction of actual bronchoscopy.
Several previous studies have shown that computer-based endoscopic simulators, including those for bronchoscopy, esophagogastroduodenoscopy, and colonoscopy, provide a favorable degree of virtual realism with regard to visual and mechanical parameters, and have an inherent capability of distinguishing varying levels of competence at actual endoscopy. This study also demonstrated that most of the performance parameters measured were correlated with bronchoscopic experience. When compared with novice bronchoscopists, expert bronchoscopists had a shorter total procedure time, a higher percentage of segments visualized (100%) and of segments and pathologies identified, a lower chance of repeated bronchial segment entry or of bronchoscope tip collision with airway walls, and a lower number of times when oral instruction was required. The most reliable parameter to differentiate novice from expert bronchoscopists was the percentage of segments identified. To identify a bronchial segment, the participant had to visualize and name the segment correctly. Familiarity with 3D anatomy is required to correctly identify a given segment during the bronchoscopic procedure. Novice bronchoscopists usually got lost during repeated insertion, withdrawal, and rotation of the CBBS. This explains their ability to visualize most of the segments but not to name them correctly (91% visualized vs. only 35% identified), even though they were very familiar with the two-dimensional anatomy. These results suggest that knowledge of 3D tracheobronchial anatomy can better be obtained by repeated hands-on practice rather than by conventional observation-based training methods.

Our initial speculation that the total dose of lidocaine used and the number of times that physical instruction was indicated during CBBS performance would be correlated with the skill level of the participant was not borne out. This may be attributed to having reminded participants that frequent injection of lidocaine would cause the patient to develop cardiac arrhythmia and hypoxemia. We observed that novice bronchoscopists used lidocaine conservatively even when it was indicated. In contrast to novice bronchoscopists, the timing of lidocaine usage among the expert bronchoscopists was more optimal, although the total dose used in the two groups was not significantly different. The number of times physical instruction was required was rare in the two groups. The reasons could be: (1) manipulation of the CBBS is not difficult, and (2) there is no patient at risk during the CBBS procedure, such that oral instruction is usually enough to solve the problem.

The satisfaction survey of novice bronchoscopists indicated that most were very satisfied with the CBBS training system. The hands-on opportunity allowed the novice bronchoscopist to be a participant rather than an observer. The availability of different kinds of simulated patients with a variety of pathologies also made the bronchoscopy simulation challenging and interesting. However, the results also indicated that CBBS trainees were no more satisfied than conventional trainees in the resulting increased knowledge of pathologies. Expert bronchoscopists also described that the pathologies had the lowest realism score of the CBBS system. Surveys of both novices and experts suggested that the simulation of pathologies by the system was not very realistic and requires further improvement.

Although CBBS has the potential to distinguish different experience levels, transfer of skill from CBBS to real procedures was not evaluated in this study. A previous study has demonstrated that a short, focused course of instruction using a virtual bronchoscopy simulator enabled novice trainees to attain a level of basic skill in performing diagnostic bronchoscopy. In addition, computer-based simulator training also enhances patient comfort during real endoscopic procedures. Further study involving blinded assessment is required to validate training with this CBBS to provide such an effect.

In addition to allowing students to practice their bronchoscopy skills, the CBBS could play an important role in training. It could be used to measure the skill of the trainees, allowing a much more quantifiable assessment of their readiness to perform their first bronchoscopy. In medical
education, it could be integrated into a didactic training program, allowing development of familiarity with the instrument and unlimited practice. Another important area is case management skill. Complications can be programmed into the simulation to train the physician to respond in a timely and appropriate manner. This is analogous to pilots using flight simulators to practice their response to unexpected disasters such as power failure in midair. Bronchoscopy simulation may also play a role in nonpulmonary physician education. For nonpulmonary physicians and other healthcare providers, such as bronchoscopy nurses, respiratory therapists, and intensive care personnel, an accurate simulation may be useful in teaching airway anatomy as well as allowing a better appreciation of what is involved in a bronchoscopic examination.\textsuperscript{12} Finally, bronchoscopy simulators may aid in patient education and facilitate obtaining informed consent.

In summary, the favorable results of satisfaction and realism surveys and the capability of differentiating between novice and expert bronchoscopists demonstrate that this CBBS is accurate, can increase the effectiveness of bronchoscopic training, and can effectively assess skill acquisition during training. Further studies to determine if the experience and skill learned using this CBBS are transferable to real bronchoscopy, and to determine the role of CBBS in the bronchoscopic training curriculum are required.

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3. **Chairman’s Office**: King-Jen Chang, MD, PhD (Chairman); Hsin-Ju Cheng and Ju-Mei Shao (Administrative Assistants).

**Executive Committee**: King-Jen Chang, MD, PhD (Chairman); Feipei Lai, PhD (Computer and Information); Yi-Ping Hung, PhD (Networking and Multimedia); Yio-Wha Shau, PhD (Biotechnology); Po-Huang Lee, MD, PhD (Medical); Yung-Chie Lee, MD, PhD (Medical); Hong-Shiee Lai, MD, PhD (Medical).

**Technology and Development**: Feipei Lai, PhD; Yi-Ping Hung, PhD; Jin-Siang Shaw, PhD; Yio-Wha Shau, PhD; Chao-Wang Hsiung, MPH.

**Clinical Research**: Jin-Shing Chen, MD, PhD; Hsao-Hsun Hsu, MD; I-Ru Lai, MD, PhD; Hao-Chih Tai, MD.

**References**