Simulation-Based Training in Flexible Bronchoscopy and Endobronchial Ultrasound-Guided Transbronchial Needle Aspiration (EBUS-TBNA): A Systematic Review

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Keywords

Simulation · Training · Flexible bronchoscopy · Endobronchial ultrasound · Bronchoscopy education

Abstract

Background: The use of simulators in a training programme for technically challenging procedures has the advantages of lowering the risk of patient complications while helping the trainees with the initial part of their learning curve. **Objectives:** The aim of this study was to perform a systematic review of simulation-based training in flexible bronchoscopy and endobronchial ultrasound (EBUS). **Methods:** We identified 1,006 publications in the PubMed database and included publications on flexible bronchoscopy below the carina and EBUS involving hands-on simulation-based training. Publications were excluded if they were written in languages other than English, if paediatric airways were involved or if they were not journal articles. The screening process was performed by 2 individuals, and a third reviewer made the final decision in case of disagreement. **Results:** We included 30 publications. The studies included participants

of varying experience and most commonly used a virtual reality simulator as a training modality. Assessment of the participants' skills was based on simulator metrics or on an assessment tool. Some studies included performance on patients for assessment of the operator after training on a simulator. **Conclusions:** Simulation-based training was demonstrated to be more efficient than the traditional apprenticeship model. Physical models and virtual reality simulators complement each other. Simulation-based education should be based on a mastery learning approach and structured as directed self-regulated learning in a distributed training programme.

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Introduction

Flexible bronchoscopy with biopsy and endobronchial ultrasound-guided transbronchial needle aspiration (EBUS-TBNA) are important invasive procedures for the diagnosis and staging of patients with lung cancer [1] and other diseases. The procedures are technically chal-

Fig. 1. Literature search strategy, PRISMA guidelines. EBUS, endobronchial ultrasound.

linging, and the diagnostic yield increases with experience [2, 3]. Invasive procedures are traditionally taught using the apprenticeship model, where trainees practice on patients supervised by an experienced colleague, but this method of teaching increases the rate of patient complications, the procedure time, and the amount of sedation used [4]. An alternative approach to training on patients is simulation-based training, where trainees practice skills in a controlled environment that is inherently patient safe. The idea of using simulators, including virtual reality, synthetic phantoms, and cadaveric models, is to help the learner with the initial part of the learning curve [5], thus reducing complications due to inexperience and allowing the trainee to learn from errors in a forgiving and stress-free environment [6–8]. Medical education, including simulation-based training, should be based on best available evidence, with standards similar to those that guide patient treatment. The aim of this study was to provide a systematic overview of the available literature regarding simulation-based training in flexible bronchoscopy and EBUS-TBNA and to explore the optimal training programme and assessment method.

Materials and Methods

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [9]. We identified a total of 1,006 publications from the PubMed database using the following search string: (bronchoscopy OR endobronchial ultrasound OR EBUS) AND (simulat* OR training). Two independent reviewers searched the publications for eligibility. We included publications on flexible bronchoscopy below the carina and EBUS involving hands-on simulation-based training on virtual reality simulators, synthetic phantoms/models and/or cadaveric models. Publications were excluded if they were written in languages other than English, if the training was performed on paediatric airways or if the publication was an expert opinion, a commentary, a poster or similar. The full text of a publication was screened when necessary. In the event of disagreement between the 2 reviewers, a third reviewer made the final decision regarding inclusion. Based on this method, 38 publications were selected for full-text review. Several studies were subsequently identified that did not fulfil inclusion criteria: hands-on simulation-based training was not included in 2 publications, the bronchoscopy training was done with a rigid bronchoscope in 4 publications and the training did not include bronchoscopy below the carina (but rather only training in intubation) in 2 publications. Therefore, these 8 publications were excluded, resulting in 30 remaining publications (Fig. 1). As a final step, we reviewed the reference lists of the 30 publications to search for missed studies. No additional publications were identified with this method.

Table 1. Publications on flexible bronchoscopy: study characteristics

First author [ref.], year	Category	Modality	Study design	Participants, <i>n</i>	Competence level of participants	Assessment of skill ^a	Outcome measures
Bjerrum [10], 2016	TM	VR	RCT	20	trainees	simulator metrics	performance on simulator
Byrne [11], 2016	SIM	manikin	des	–	“experienced bronchoscopists”	none	expert opinion
Chen [12], 2016	SIM	human cadaver	des	4	“experienced bronchoscopists”	none	expert opinion
Colella [13], 2015	AT	VR	NR	29	MDs, students	motion analysis	performance on simulator
Pastis [14], 2014	SIM	VR	val	20	MDs, trainees	simulator metrics	performance on simulator, expert opinion, trainee opinion
Bjerrum [15], 2014	TM	VR	RCT	36	students	simulator metrics	performance on simulator
Krogh [16], 2013	SIM	VR	RCT	20	students	blinded assessment	performance on simulator
Konge [17], 2011	AT	VR	val	42	MDs, Students	1 non-blinded, 2 blinded raters	performance on simulator
Konge [18], 2011	SIM	VR	val	30	MDs	simulator metrics	performance on simulator, expert opinion
Colt [19], 2011	AT	manikin	NR	24	trainees	1 non-blinded rater	performance on simulator
Wahidi [20], 2010	TM	VR, patients	NR	41	trainees	1 non-blinded rater	performance on patients
Davoudi [21], 2010	SIM	VR, manikin	NR	44	MDs, other	–	expert opinion
Goldberg [22], 2009	SIM	animal	NR	12	MDs, Trainees	–	expert and trainee opinion
Deutsch [23], 2009	SIM	manikin, VR, animal	NR	36	trainees	–	trainee opinion
Davoudi [24], 2008	AT	VR	val	22	MDs, trainees, students	2 non-blinded raters	performance on simulator
Di Domenico [25], 2007	SIM	manikin	des	–	–	–	expert opinion
Chen [26], 2006	SIM	VR	val	30	MDs	simulator metrics	performance on simulator, expert opinion
Agrò [27], 2005	TM	model, manikin	NR	5	MDs	procedural time	performance on simulator
Martin [28], 2004	SIM, TM	model	NR	40	MDs, trainees, other	2 blinded raters	performance on participants
Blum [29], 2004	TM	VR	RCT	13	trainees	1 non-blinded rater, self-evaluation	performance on patients
Moorthy [30], 2003	SIM	VR	val	18	“novices,” “experienced bronchoscopists”	simulator metrics	performance on simulator
Ost [31], 2001	SIM, TM	VR	val, RCT	28, 6	MDs, trainees, other	simulator metrics, 1 non-blinded rater	performance on simulator, performance on patients
Colt [32], 2001	TM	VR, manikin	NR	9	trainees	simulator metrics, 1 non-blinded rater	performance on simulator

TM, studies comparing training methods; SIM, studies developing and/or exploring simulation equipment; AT, studies developing and/or exploring assessment tools; VR, virtual reality simulator; manikin, anatomical simulator of synthetic material; model, non-anatomical model simulator; RCT, randomized controlled trial; des, descriptive study; NR, non-randomized; val, validity study; trainee, resident/fellow; MD, physician/specialist; students, medical students. ^a Method of assessment if the study involved an assessment of skill.

Table 2. Publications on endobronchial ultrasound: study characteristics

First author [ref.], year	Category	Modality	Study design	Participants, <i>n</i>	Competence level of participants	Assessment of skill ^a	Outcome measures
Konge [33], 2015	AT, TM	VR, patients	val, RCT	18	MDs	3 blinded raters	performance on patients
Stather [34], 2013	TM	VR	NR	14	trainees	simulator metrics	performance on simulator
Konge [35], 2013	AT	VR	val	22	MDs	simulator metrics	performance on simulator
Stather [36], 2012	TM	VR, animal models	RCT	12	MDs, trainees	simulator metrics	performance on simulator
Stather [37], 2012	TM	VR, patients	NR	8	trainees	1 non-blinded rater	performance on patients
Stather [38], 2011	TM	VR, patients	NR	13	trainees	simulator metrics	performance on simulator
Stather [39], 2011	SIM	VR	val	22	MDs, trainees	simulator metrics	performance on simulator

AT, studies developing and/or exploring assessment tools; TM, studies comparing training methods; SIM, studies developing and/or exploring simulation equipment; VR, virtual reality simulator; val, validity study; RCT, randomized controlled trial; NR, non-randomized; MD, physician/specialist; trainee, resident/fellow. ^a Method of assessment if the study involved an assessment of skill.

Results

A total of 30 publications [10–39] were included. We divided them into 2 groups: publications on flexible bronchoscopy ($n = 23$) and publications on EBUS ($n = 7$). Tables 1 and 2 show key features.

In total, there were 10 validation studies [14, 17, 18, 24, 26, 30, 31, 33, 35, 39], 7 randomized trials [10, 15, 16, 29, 31, 33, 36] and 3 descriptive studies [11, 12, 25]. The remaining studies [13, 19–23, 27, 28, 32, 34, 37, 38] either tested various training methods [20, 27, 28, 32, 34, 37, 38], simulators [21–23, 28] or a new approach to skills assessment [13, 19].

The study participants varied in their experience level and included medical students and postgraduate residents or fellows with little or no experience in flexible bronchoscopy or EBUS, as well as experts in one or both fields. Four studies included other healthcare professionals [21, 28, 30, 31].

The most common modality for training was virtual reality simulators, most frequently consisting of a proxy flexible bronchoscope that could be inserted into an interface, as well as a computer with simulation software that could display a virtual image of the bronchi. Some of the simulators also had a tactile feedback mechanism and/or the ability to simulate normal human activities (i.e., breathing, coughing, etc.) for heightening the realism. Two studies described building a low-fidelity model out of inexpensive materials [11, 25]. Other studies used animal cadavers or manikins that replicated lung anatomy to simulate a realistic bronchial tree. Some included the use of animal models [22, 23, 36], and 1 study used a human cadaver [12]. Table 3 shows an overview of the simulators used in the publications.

Flexible Bronchoscopy

We found a total of 23 publications on simulation-based training in flexible bronchoscopy (Table 1).

Studies Developing and/or Exploring Simulation Equipment

Thirteen studies either gathered validity evidence for a simulation-based test [14, 18, 26, 30, 31], compared different simulators [21, 23, 28] or described the effectiveness of alternative simulators, e.g., a human cadaver, a portable simulator or low-cost models [11, 12, 16, 22, 25]. When gathering validity evidence, the outcome measure that consistently differentiated novices from experts was procedure time. Other reported outcome measures were segments entered, number of bronchial wall collisions and segments correctly or incorrectly identified.

Studies Developing and/or Exploring Assessment Tools

Four studies explored assessment tools. Davoudi et al. [24] gathered validity evidence for the Bronchoscopy Skills and Tasks Assessment Tool (BSTAT) and the Bronchoscopy Step-by-Step Evaluation Tool (BSET). Konge et al. [17] developed a new assessment tool and gathered validity evidence for its ability to differentiate between varying levels of experience beyond the typical standards of novices and experts. One study used alternative measurements to assess the learners' skills [19]. An additional study explored the possibility of using a motion sensor to assess the skills of an operator [13].

Studies Comparing Different Training Methods

The remaining studies compared different methods of training. In general, these studies demonstrated that sim-

Table 3. Overview of the simulators used in the included publications

Simulator name	Simulator company	Type	Simulated procedure	Publications including this simulator
Endoscopy AccuTouch® System	CAE Healthcare, Montreal, QC, Canada	VR	FB, EBUS	[10, 15–18, 20, 21, 23, 31, 34, 36–39]
Simbionix BRONCH Mentor™	3D Systems, Cleveland, OH, USA	VR	FB, EBUS	[13, 14, 33, 35]
PreOp endoscopy simulator	HT Medical Systems, Gaithersburg, MD, USA	VR	FB	[24, 29, 30, 32]
Orsim® bronchoscopy simulator	Airway Simulation Limited, Auckland, New Zealand	VR	FB	[16]
NTUESC CBBS	National Taiwan University, Taipei, Taiwan, ROC	VR	FB	[26]
Dexter® endoscopic dexterity trainer	Replicant® Medical Simulator Ltd., Wellington, New Zealand	model	FB	[27, 28]
Choose the hole	designed by Dr. Arthur Frederick David Cole	model	FB	[28]
AirMan	Laerdal, Stavanger, Norway	manikin	FB	[27]
Airway management trainer	Laerdal, Stavanger, Norway	manikin	FB	[32]
Model No. 1815 + demonstration model No. 252500	Sawbones, Pacific Research Laboratories USA	model	FB	[19, 21]
Cadaveric model	–	–	FB	[12, 23, 36]
Constructed simulators	built by the authors	–	FB	[11, 22, 25]

NTUESC CBBS, National Taiwan University Endoscopic Simulation Collaborative Study Group Computer-Based Bronchoscopy Simulator; VR, virtual reality simulator; model, non-anatomical model simulator; manikin, anatomical simulator of synthetic material; FB, flexible bronchoscopy; EBUS, endobronchial ultrasound.

ulation-based training was an effective training method when participants were tested before and after an intervention [27, 29, 31, 32]. In addition, they showed that the skills of simulation-trained participants were similar to those who received training based on the traditional apprenticeship model [20, 29, 31, 32]. Bjerrum et al. [10, 15] published 2 randomized studies on training methods: one explored the efficiency of dyad practice [15], and the other compared different distribution practices [10]. The conclusions of these studies were that both dyad practice and practice for only 1 day led to no significant differences in effectiveness when compared to individual practice and a distributed practice of 3 weeks, respectively. Four studies assessed participants' skills when performing procedures on patients (or in 1 case, on other participants) [20, 28, 29, 31] and, thus, showed that the acquired skills were transferable. Furthermore, Wahidi et al. [20] challenged the assumption that the learning curve of flexible bronchoscopy reaches a plateau after 50 bronchoscopies and, in fact, found that this transition occurred more often after 100 bronchoscopies.

Endobronchial Ultrasound

One publication explored a simulation-based test and proved its ability to differentiate between 4 groups of trainees with varying degrees of bronchoscopy and EBUS experience [39]. Two publications gathered validity evidence for assessment tools, and 1 focused on exploring which simulator metrics could reliably differentiate between experts and novices [35]. A randomized controlled

trial [33] validated an assessment tool, the endobronchial ultrasound assessment tool (EBUSAT), which had been developed by the research group. This tool was used to assess the competency of participants trained according to the apprenticeship model as compared to those who received simulation-based training. The latter study group scored higher on the EBUSAT. Both the knowledge of anatomy and the biopsy techniques were assessed.

The remaining 4 publications focused on comparing different training methods. Two compared simulation-based training with both wet laboratory training and traditional apprenticeship training. These studies demonstrated that simulation-based training was equally effective as the other 2 approaches [36, 37]. In another study, the authors reached the same conclusion when comparing physician- and respiratory therapist-proctored training [34]. Finally, Stather et al. [38] compared learning curves of trainees who had undergone simulation training with a second group who received clinical training. The authors found that the simulation-trained group acquired skills more rapidly than the other group.

Two studies used procedural performance on patients as an outcome measure, revealing that the skills taught on a simulator were transferable to a clinical setting [33, 37].

Assessment

If a study included an assessment of a participant's skill level, this was either based on simulator metrics [10, 14, 15, 18, 26, 30–32, 34–36, 38, 39] or a test during which 1 or more raters (sometimes blinded) evaluated the par-

ticipant's performance using an assessment tool [17, 19, 20, 24, 28, 29, 31–33, 37]. While outcome measures were most often quantitative and objective, some studies incorporated subjective evaluation (sometimes as the only outcome measure) [11, 12, 14, 18, 21–23, 25, 26]. Six studies included performance on patients or other participants when assessing the participants' skills [20, 28, 29, 31, 33, 37].

Of all the publications on flexible bronchoscopy, only a few included biopsies as an essential part of the operator assessment [16–18]. Two studies used the BSTAT during which the operator might be asked to perform a biopsy as 1 of a few standard tasks [20, 24]. Finally, 2 studies included training in conventional TBNA but provided only subjective opinions regarding the simulators rather than an objective assessment of the operator performance [21, 22]. The remainder of the publications on flexible bronchoscopy studied diagnostic bronchoscopy only.

Moorthy et al. [30] found that none of the simulator metrics could differentiate novices from experts after the former group had performed 5 bronchoscopies on a simulator. Ost et al. [31] found that the metrics were not able to discriminate between intermediates and experts, while Colt et al. [32] found that novices performed equally well or even better than skilled physicians on some simulator metrics after practicing for a few hours. Furthermore, Chen et al. [26] found the simulator metrics to differentiate between participants with no bronchoscopy experience and experts but made no observation on other levels of expertise. Konge et al. [18] found that simulator metrics were too imprecise to assess the quality of a lymph node biopsy.

Discussion

Flexible bronchoscopy with biopsy and EBUS-TBNA are important tools for the diagnosis and staging of lung cancer and other diseases. These procedures should be performed with a high level of quality to maximize the likelihood of obtaining an optimal diagnostic yield, while simultaneously minimizing risks for the patient and the equipment. The ultimate intent with simulation-based training is to create the basis for an optimal treatment of the patient to improve their prognosis.

Cook and West [40] recommended caution when focusing on patient outcomes in research. It would be ideal to be able to measure the effect of the simulation-based education on the prognosis of the patient, but there are too many links from the training to the patient outcome to make this meaningful and possible. No included pub-

lications used patient outcome to measure the effect of the simulation-based training. Instead, in some studies the participants' skills were ultimately assessed while performing the procedure on patients who underwent EBUS-TBNA [33, 37] or flexible bronchoscopy [20, 28, 29, 31]. Using performance on patients as an outcome measure provides us with the assurance that the skills acquired when training on a simulator can be transferred to a clinical setting, which in turn brings us 1 step closer to our goal of providing the patient with the best care possible.

Most publications included in this review used simulator metrics as the basis for the assessment of participants. These metrics can only differentiate between complete novices and experts and should not be used to measure finer nuances of competence between these 2 extremes. An example of a simulator metric that is commonly used is "segments entered." Colt et al. [32] found that the novices entered more segments than more experienced physicians, Moorthy et al. [30] showed no difference between novices and experts after 5 simulated bronchoscopies, and Konge et al. [17] also found this metric to be of no value for the discrimination between skill levels. Apparently, novices learn to enter almost all segments after a short time of practice, but this skill is clinically irrelevant if they cannot identify which segment or anatomical structure they are visualizing. For EBUS-TBNA it is possible to use the metrics with caution [35].

Some of the publications assessed the participants with a non-blinded rater. This automatically lowers the level of evidence as the risk of bias is very high when raters are non-blinded [41].

The vast majority of the publications focused on teaching the anatomy, whereas only a few supplemented this with training in the biopsy procedure. A perfect biopsy technique does not make sense if the operator does not know where the biopsy was taken. Similarly, it does not make sense to know the anatomy if you are not able to take biopsies. Krogh et al. [16] and Konge et al. [17] used the same assessment method, which ensures a comprehensive rating not only because of the equal emphasis on both anatomy and biopsy taking, but also because of its ability to discriminate between varying degrees of experience.

Simulation-based training provides us with a great tool for learning procedures, in this case for flexible bronchoscopy with biopsy and EBUS-TBNA. There is, however, still a long way to go in establishing an effective curriculum for simulation-based training. An ideal training programme should include the following: directed self-regulated learning, distributed learning, and mastery learning [42, 43]. Directed self-regulated learning, which provides

the trainees with the chance to learn from their own experiences and mistakes, has been shown to be an effective learning method in simulation [44]. Bjerrum et al. [10] explored practice distribution, but only with flexible bronchoscopy, and found no significant differences between the 2 groups with regard to their subsequent performance on the simulator. This finding contradicts other studies which have demonstrated that distributing learning over a longer period of time proved highly efficient [45–47]. However, the study by Bjerrum et al. [10] used only the insensitive simulator metrics, which could explain the negative findings. Mastery learning, where the trainee must reach a certain level of competence before advancing to the next step, includes simulation-based tests with solid evidence of validity and is an essential part of simulation-based training [48]. Dyad practice, where 2 trainees practice together on the same simulator using the same time span as an individual would, was proved to be as effective as individual practice [49, 50]. In 1 of our included studies [15], the dyad practice trainees subsequently performed as well as the individual trainees. This approach to training is, therefore, possible, even though it is less flexible because the 2 trainees must be available at the same time.

To the best of our knowledge, no studies on simulation-based training in oesophageal ultrasound-guided fine-needle aspiration (EUS-FNA) exist, though there is a significant need for research in this area. EBUS-TBNA and EUS-FNA complement each other [1, 51]. The use of the EBUS endoscope in the oesophagus (EUS-B-FNA) is rapidly gaining acceptance [1]. It is, therefore, surprising that no virtual reality EUS-FNA simulator exists, while there are several EBUS simulators on the market (Table 3). Trainees have to practice on phantoms and patients. A recent national needs assessment study showed EUS-FNA to rank fourth on the list of technical skills that should be included in a simulation-based curriculum [52].

Strengths and Limitations

Notable strengths of our review are that it was conducted systematically by 2 independent reviewers and that the authors include experts in interventional pulmonology and simulation-based training. A limitation is that it was not possible to perform a meta-analysis due to the heterogeneity of the included studies.

Conclusion and Recommendations

Studies included in this review revealed that trainees receiving simulation-based training in flexible bronchoscopy and EBUS-TBNA acquired similar or better skills when compared to trainees with apprenticeship training. Simulation-based training is more efficient than apprenticeship training during the beginning of the learning curve because the patients are exposed to fewer risks due to inexperience of the operator, and it should thus be mandatory prior to performing procedures on patients. Evidence suggests that physical models (phantoms, etc.) and virtual reality simulators supplement each other, and similar skills can be taught by both modalities. Simulator metrics can be used with caution as an assessment of competence for EBUS-TBNA but should not be used for flexible bronchoscopy as they are too insensitive. Studies from other areas than bronchoscopy and EBUS-TBNA suggest that training could be optimally structured as directed self-regulated learning in a distributed training programme, which we therefore recommend for training in flexible bronchoscopy as well as EBUS. Finally, simulation-based training should be based on a mastery learning approach, during which simulator training continues until competency is achieved, as assessed by an expert rater (flexible bronchoscopy) and simulator metrics (EBUS).

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