Eveline Gerretsen

Learning to **navigate** the **bronchial tree**

Considerations for simulation-based bronchoscopy training

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Learning to navigate the bronchial tree:
considerations for simulation-based bronchoscopy training

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Chapter 1

General introduction

The uptake of simulation-based training (SBT) in medical education has significantly increased in the 21st century [1]. Concerns for patient safety primarily drive this departure from traditional apprenticeship methods, which involve medical trainees practicing procedures directly on patients [2]. Additionally, reductions in working hours have limited on-the-job training opportunities for medical trainees [3,4], highlighting the need for alternative training modalities [5]. Simulators enable trainees to practice their knowledge, skills and attitudes in a risk-free environment at their convenience, without compromising patient safety [6]. A cornerstone of SBT is experiential learning theory, which emphasizes the crucial role of concrete experience, reflecting on the experience and active experimentation [7]. According to this theory, trainees learn most effectively when they actively engage in experiences, reflect on their actions and apply their new knowledge. Medical simulators provide trainees with the opportunity to engage in simulated clinical scenarios, allowing them to actively participate in the learning process and reflect on their actions. This enables trainees to enhance their proficiency in various clinical skills, better preparing them for patient care encounters in real-life settings [8].

With the increasing implementation of SBT in medical education, the field of flexible bronchoscopy (FB) training has also employed simulators as a tool for skill training. FB is a procedure that allows the operator (mostly a pulmonologist) to investigate and perform diagnostic or therapeutical procedures in the bronchial tree. It is essential for various indications, such as for example the evaluation of suspected lung cancer, lung parenchymal infiltrates, hemoptysis and foreign body removal [9,10]. A bronchoscopy can be performed after the application of local anesthesia to the bronchial tree, with mild or deep sedation, or general anesthesia. This allows the operator to introduce a flexible bronchoscope into the airways, inspect the airways and perform diagnostic or therapeutic procedures. To perform this procedure adequately, a thorough knowledge of the indications, contra-indications, the anatomy of the bronchial tree, and the appropriate skills to navigate the bronchoscope through the bronchial tree are essential. If one or more competencies are lacking, a bronchoscopy can become a bothersome and even unsafe procedure for the patient. Bronchoscopists should therefore be adequately trained to minimize patient risks and avoid patient discomfort. The conventional apprenticeship training method, where residents performed clinical bronchoscopies under supervision, was associated with increased procedure duration [11] and scope damage [12] compared to when more experienced pulmonologists performed the procedure. Moreover, patients undergoing bronchoscopy during a trainee's first training semester had an increased complication risk [11,13]. These limitations contributed to the increased adoption of simulators in bronchoscopy training, with a diverse array of simulators currently being employed, including 3D-printed airway models, animal models and high-fidelity virtual reality simulators [14–17]. Although several reviews on bronchoscopy SBT programs exist [18–21], their interpretation is somewhat hindered by narrative designs, lack of study quality assessments and variations in included studies' settings and types of bronchoscopy. Furthermore, no reviews have explored the effectiveness of instructional features in flexible bronchoscopy SBT programs, which has hindered the development of specific guidelines for educators on structuring of their programs. To provide a comprehensive overview of existing literature, a systematic review was conducted on the effectiveness of FB SBT programs and their instructional features, which is described in **Chapter 2**.

Studies in the FB SBT field commonly use a pretest-posttest design, where participants perform a test before and after the simulation intervention. This design is mostly chosen due to ethical concerns associated with a scientifically preferred randomized controlled design study. In this design, trainees in the control group would have to practice their first basic bronchoscopy skills on real patients, which is considered unethical when a simulator is available [22]. However, this pretest-posttest design has some drawbacks, including the potential influence a pretest might have on a trainee's posttest outcomes. This phenomenon, known as the pretest effect or pretest sensitization [23,24], may in turn lead to an overestimation of intervention effects. To our knowledge, no FB SBT studies have explored the possibility of this pretest effect. Therefore, in **Chapter 3**, we investigated the possible extent of this pretest effect and described the possible implications for future FB SBT studies.

Considering the perceived advantages of SBT, the Dutch Association of Chest Physicians (NVALT) decided to implement a one-day FB SBT course for first-year pulmonology residents in 2020. Given that SBT programs are most effective when implemented in the standard curriculum [5], it was decided to make the training program mandatory and implement it nationwide, eventually involving seven simulation centers and 14 trainers. The training program was developed through collaboration with all trainers, the research team and two internationally renowned colleagues with extensive expertise in SBT. Aligned with practices informed by simulation research, the training program's development stemmed from predefined objectives [5], being 1) navigating adequately through the bronchial tree maintaining proper scope handling and 2) proficiency in entering and identifying all airway segments accurately. These objectives were based on a cognitive task analysis conducted in a prior study [25], which confirmed the appropriateness of training these skills on a virtual reality simulator. Additionally, it was decided that each training day would involve two residents, ensuring small group sizes, and the training program was structured to facilitate dyad practice, two factors that bronchoscopy trainees highly valued according to previous research [26]. Furthermore, effective clinical performance requires integration of theoretical knowledge and practical skills [27]. Therefore, it was determined that all trainees had to acquire adequate basic theoretical bronchoscopy knowledge before attending the training, including knowledge of indications, contraindications, bronchial anatomy, premedication, topical analgesia and sedation. An anatomy exam and a theoretical knowledge exam were developed and critically reviewed by experts and served as a tool to assess the trainees' readiness for practical bronchoscopy training. The development of and collection of validity evidence for these exams is described in **Chapter 4**.

While several studies have examined the effectiveness of FB SBT programs and reported positive outcomes, most studies were low-powered and conducted in a single-center setting only [28], raising questions on their generalizability. Interventions proven successful in such environments may not necessarily translate to comparable success in real-world, more complex training environments [29]. Indeed, research on SBT in laparoscopy has shown that an implementation gap in SBT still exists [30]. Given the involvement of the seven simulation centers and their trainers, as well as the anticipated high number of residents expected to participate in the NVALT training program due to its mandatory nature, this training initiative presented a valuable opportunity to investigate the real-world effectiveness of a large-scale implementation of an FB SBT program. **Chapter 5** describes the effectiveness of this training program in improving novice residents' bronchoscopy skills.

Our positive experience with the FB SBT course for pulmonology residents has encouraged us to collaborate with the developers of a FB SBT course for intensivists at the Maastricht University Medical Center+, launched in 2019. **Chapter 6** provides a detailed description of the implementation and evaluation of this training program. By sharing our experiences with the implementation of this training program, including the pitfalls we encountered, we trust that these will serve as a valuable resource for educators wishing to establish similar training programs for intensivists.

Table 1 shows an overview of the empirical studies in the different chapters. Finally, in the general discussion presented in **Chapter 7**, the main findings of the different studies are summarized and discussed in light of existing literature.

Table 1: Overview of studies in this thesis.

Chapter	Title	Study design	Aim
2	Effectiveness of Flexible Bronchoscopy Simulation-Based Training: A Systematic Review	Systematic literature review	To summarize the evidence of FB SBT programs and instructional features effectiveness
3	The influence of the pretest effect on posttest scores in a bronchoscopy simulation setting	Single group pretest-posttest study	To determine the existence of a pretest effect in a FB SBT setting
4	Development and Validation of two Bronchoscopy Knowledge Assessments	Experience-level cross-sectional study	To describe the development and validation of the anatomy and theoretical bronchoscopy exam
5	Basic Bronchoscopy Competence Achieved by a Nationwide One-day Simulation-based Training	Single group pretest-posttest study	To determine the impact of the NVALT training program on residents' skills
6	Development, implementation and evaluation of a bronchoscopy simulation training program for intensive care Fellows and intensivists in the Netherlands	Retrospective evaluation study	To share our insights with the development and implementation of the FB SBT course for intensivists

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Chapter 2

Effectiveness of Flexible Bronchoscopy Simulation-Based Training: A Systematic Review

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Abstract

Background: The implementation of simulation-based training (SBT) to teach flexible bronchoscopy (FB) skills to novice trainees has increased during the last decade. However, it is unknown whether SBT is effective to teach FB to novices and which instructional features contribute to training effectiveness.

Research Question: How effective is FB SBT and which instructional features contribute to training effectiveness?

Study Design and Methods: We searched Embase, PubMed, Scopus, and Web of Science for articles on FB SBT for novice trainees, considering all available literature until November 10, 2022. We assessed methodological quality of included studies using a modified version of the Medical Education Research Study Quality Instrument, evaluated risk of bias with relevant tools depending on study design, assessed instructional features, and intended to correlate instructional features to outcome measures.

Results: We identified 14 studies from an initial pool of 544 studies. Eleven studies reported positive effects of FB SBT on most of their outcome measures. However, risk of bias was moderate or high in eight studies, and only six studies were of high quality (modified Medical Education Research Study Quality Instrument score ≥ 12.5). Moreover, instructional features and outcome measures varied highly across studies, and only four studies evaluated intervention effects on behavioral outcome measures in the patient setting. All of the simulation training programs in studies with the highest methodological quality and most relevant outcome measures included curriculum integration and a range in task difficulty.

Interpretation: Although most studies reported positive effects of simulation training programs on their outcome measures, definitive conclusions regarding training effectiveness on actual bronchoscopy performance in patients could not be made because of heterogeneity of training features and the sparse evidence of training effectiveness on validated behavioral outcome measures in a patient setting.

Introduction

Use of simulation in health professions education has increased significantly over the past 2 decades [1]. This shift from the traditional apprenticeship model (see one, do one, teach one) toward simulation-based training (SBT) is largely the result of concerns for patient safety [2,3]. In general, the apprenticeship method, and more specifically, flexible bronchoscopy (FB) training, are associated with a higher complication risk [4,5] and increased patient discomfort [6]. Hence, a shift to SBT might be desirable.

Currently, a variety of FB simulators are used for bronchoscopy training (e.g., animal models [7], 3-D printed airway models [8], high-fidelity virtual reality simulators [9,10]). To date, four reviews on bronchoscopy training programs (TPs) using simulators have been published [2,11, 12, 13]. The systematic review by Kennedy et al [2] concluded that SBT was effective in comparison with no training. The authors also assessed the presence of 10 key instructional features, as identified in an earlier review on features of medical simulation TPs [14]. The interpretation of the Kennedy et al [2] review is somewhat hampered by the inclusion of a variety of different simulation methods for different types of bronchoscopies (e.g., rigid bronchoscopy, FB, endobronchial ultrasound). Furthermore, the studies' settings were heterogeneous (e.g., in an otolaryngology or anesthesiology setting). Bronchoscopy in these settings requires less detailed navigation competencies compared with FB in a pulmonology setting [9]. Three additional reviews have been published since then on FB SBT [11-13], but their interpretation is also hampered by their narrative designs and lack of systematic study quality assessments. In addition, none of these three reviews looked at the effectiveness of instructional features present in the included TPs.

Based on these reviews, there is still no clear-cut answer to the basic question of whether FB SBT is effective in improving basic FB skills of novice pulmonology trainees and which instructional TP features might contribute to training effectiveness. In this review, we therefore aim (1) to summarize the current evidence of the effectiveness of SBT on improving novice bronchoscopists' basic FB skills, taking into account quality of included studies, and (2) to give an overview of the general and instructional features of the investigated TPs. Furthermore, we describe the relation between instructional features and outcomes to identify the most effective training strategies.

Study design and methods

This review was written in compliance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines [15]. Because only publicly available data were used and no human subjects were involved, institutional review board approval was not required.

A search was performed in PubMed, Embase, Scopus, and Web of Science, encompassing all available articles up until November 10, 2022, using the search strategies developed in collaboration with an experienced research librarian (Supplemental material 1). The search was composed of relevant terms related to bronchoscopy, simulation training, and competence. No language criteria were applied. The following selection criteria were used for inclusion of studies into the final analysis: (1) the study design had to be a pretest-posttest, two-group nonrandomized, or randomized design; (2) the study had to include novice trainees regarding bronchoscopy experience; and (3) the intervention had to include at least basic FB SBT, where the simulator is a tool or device with which the trainee physically interacts to simulate an FB. Studies reporting only trainee-reported outcome measures were excluded.

Two reviewers (E. C. F. G. and A. C.) independently performed all evaluations regarding screening and data extraction. Only full texts were considered. In case of discrepancy, a consensus meeting was planned. In case no consensus could be achieved, a third reviewer (F. W. J. M. S.) made the final decision.

First, the reviewers screened all titles and abstracts of studies from the search results against the inclusion criteria. After achieving consensus on which articles to include, they screened reference lists of those articles for other possible relevant articles.

Second, the following characteristics of the full texts of included papers were assessed: study design, number of participants and their level of education, simulator modality, comparator, outcome measures, and intervention's effects on the outcome measures.

Articles that fully met all inclusion criteria were included for analysis.

The reviewers also evaluated on which Kirkpatrick level [16] outcome measures were assessed. This is a four-level model to evaluate training impact: reaction (level 1), learning (level 2), behavior (level 3), and results (level 4) [17]. In a simulation training setting, level 1 refers to participants' satisfaction with the training (not applicable in our study because these studies were excluded), level 2 refers to an improvement in skills (an improvement in outcomes in a simulation setting), level 3 learning is suggested when on-the-job behavior is improved (an improvement in bronchoscopy performance in a patient setting), and level 4 refers to improvement in patient outcomes [18] (e.g., less discomfort, fewer complications).

To prevent bias, the name of the journal, authors, abstract, and discussion sections were removed from the articles for the three reviewers in all their further evaluations. The reviewers then assessed the methodological quality of studies using the modified Medical Education Research Study Quality Instrument (mMERSQI) [19]. A score of 4.5 to 8.5 indicates low quality, 9.0 to 13.0 indicates moderate quality, and 13.5 to 18.0 indicates high quality [20]. This tool was adapted on the validity of the evaluation instrument domain because this domain was considered not fully applicable for the current review because of it being open to interpretation in this setting. Therefore, this domain was transformed into a single known-groups comparison parameter to evaluate the validity of the evaluation instrument, for which a positive score was given if the instrument had any (referred) proven validity in terms of a known-groups comparison. Considering the maximum score with our mMERSQI tool was 2.0 points lower than the original one, we adapted the interpretation of the scores regarding quality accordingly: 4.5 to 8.0 indicating low quality, 8.5 to 12.0 indicating moderate quality, and 12.5 to 16.0 indicating high quality.

Risk of bias (RoB) was determined with different tools depending on study design [21,22] (Table 1). For each study, the reviewers calculated how many items they could answer positively, where a positive score for an item means that the study had a low RoB for that item. Next, they divided the total number of positive items by the number of applicable items for that study and transformed all scores to a final score on the original scale of the RoB tool.

Table 1: Risk of bias tool used for each study design.

Study design	Risk of bias tool	Reference	Maximum score
Pre-test post-test	Quality Assessment Tool for Before-After (Pre-Post) Studies With No Control Group	[22]	12
Two-group non-randomized	Critical Appraisal Tool for Quasi-Experimental Studies (non-randomized experimental studies)	[21]	9
Randomized controlled trial	Quality Assessment of Controlled Intervention Studies	[22]	14

Finally, all studies were carefully assessed for the general and instructional features listed in Table 2. Features not explicitly mentioned in a study were assumed not to be present. In case the reviewers could not extract all characteristics from the publication, they contacted the authors to request further information.

Although a meta-analysis was planned, this proved impossible because of the high level of heterogeneity of the interventions and outcomes in the included studies [23]. Therefore, the reviewers evaluated the methodological quality and characteristics of all studies and related these to their results.

Table 2: General and instructional features and definitions.

Feature category	Feature	Definition
General	Duration	Training duration in hours and days
	Assessment by	Assessment by simulator, observer or both
	Observer instruction	Observer instruction described
	Validity evidence reported/referred	Use of validated assessment tool/ procedure or referred to known-groups comparison for the assessment tool/ procedure
Instructional design*	Clinical variation	Multiple different scenarios were present
	Curriculum integration	The training was a part of the curriculum
	Feedback	Feedback was provided by an instructor
	Group practice	Training occurred in a group
	Individualized learning	The training could be tailored to the trainee depending on individual performance
	Mastery learning	The trainee must attain a predefined level of performance
	Prestudy	Participants had to study or watch a video or presentation before the training
	Range in task difficulty	There was a variation in task difficulty

*These features were partially based on a study from Issenberg et al [14] from 2005. Although initially planned, it was decided to leave out the following three features: (1) multiple learning strategies (because no clear-cut definition of a learning strategy could be found), (2) number of learning modalities (because if training programs included more learning modalities, it was always because of videos or books being present, which was already taken into account in prestudy), and (3) repetition (because the opportunity to repeat a task multiple times is almost always possible when training on a simulator).

Results

The search yielded 544 articles after removal of duplicates. Initially, 18 studies ended up meeting the inclusion criteria (Fig 1). Reference list analysis of those studies did not lead to any other relevant articles. After evaluating the full texts of these studies, the reviewers were undecided about five studies. The third reviewer excluded four of those studies because the design or the participants' experience level did not meet the inclusion criteria [24-27].

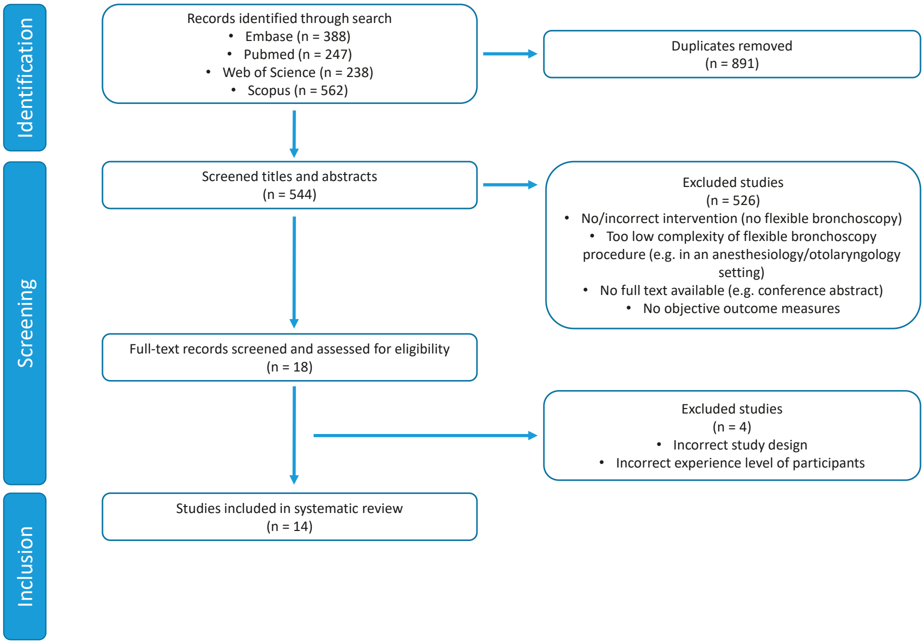

Figure 1: Flow diagram of the systematic review.

Methodological quality of studies was moderate to high, with mMERSQI scores ranging from 10 to 14 on a 16-point scale (mean ± SD, 12.2 ± 1.2) (Table 3) [6,9,10,28-38] Six studies had a high mMERSQI score (≥ 12.5) [28- 33]. The score differences were mainly caused by differences in study design.

Table 3: Study characteristics of included studies.

Study	Design	No. of participants (IG/CG)*	Experience level	Simulator modality	Comparator	Outcome measures	mMERSQI
Colt et al [6]	P-P	5	novice pulmonary & critical care medicine fellows	VR	NA	Simulator ("Learning")	11
Ost et al [28]	RCT	6 (3/3)	novice pulmonary fellows	VR	Conventional training	Patient ("Behavior")	13
Blum et al [29]	RCT	10 (5/5)	first-year surgical residents	VR	No training	Patient ("Behavior")	13
Wahidi et al [33]	2G-NR	44 (22/22)	novice pulmonary fellows	VR	Conventional training	Patient ("Behavior")	14
Colt et al [31]	P-P	24	novice pulmonary & critical care fellows	Unknown	NA	Simulator ("Learning")	13
Bjerrum et al [35]	P-P	47	medical students	VR	NA	Simulator ("Learning")	12
Krogh et al [32]	RCT	20 (10/10)	medical students	VR	No training	Simulator ("Learning")	13.5
Bjerrum et al [10]	P-P	36	medical students	VR	NA	Simulator ("Learning")	12
Bjerrum et al [36]	P-P	20	physicians in training	VR	NA	Simulator ("Learning")	12
Gopal et al [37]	P-P	47	medical students	VR	NA	Simulator ("Learning")	11.5
Veaudor et al [9]	P-P	8	novice first-year pulmonology residents	VR	NA	Simulator ("Learning")	10
Feng et al [34]	P-P	28	medical students	Part-task trainer	NA	Simulator ("Learning")	11
Schertel et al [38]	P-P	54	medical students	VR	NA	Simulator ("Learning")	11
Siow et al [30]	2G-NR	18 (8/10)	pulmonary medicine residents	VR	Conventional training	Patient ("Behavior")	14

2G-NR = two-group nonrandomized; CG = control group; IG = intervention group; mMERSQI = modified Medical Education Research Study Quality Instrument; NA = not applicable; P-P = pretest-posttest; RCT = randomized controlled trial; VR = virtual reality. *For pretest-posttest studies, only one number is shown because those studies do not have a CG.

Table 3 shows study characteristics. Most (n = 9) used a pretest-posttest design, and the number of participants in all included studies ranged from five to 54. Twelve studies used a virtual-reality simulator [6,9,10,28-30,32,33,35-38], one study used a part-task trainer [34] and for one study, the reviewers could not extract the used simulation equipment from the text [31]. Ten studies measured outcomes in a simulation setting [6,9,10,31,32,34-38] (e.g., number of wall contacts, [modified] validated Bronchoscopy Skills and Tasks Assessment Tool [BSTAT]) [39]. Four studies measured Kirkpatrick (behavioral) level 3 outcomes (e.g., BSTAT for a bronchoscopy performed on a patient) [28-30,33].

RoB scores of included studies are described in Table 4. RoB scores of pretest-posttest studies ranged from 4.4 [37,38] to 9.6 [36] on a 12-point scale (mean ± SD, 6.4 ± 1.8). Only two studies [10,36] had relatively high RoB scores (8.4 and 9.6) and were therefore considered to have a low RoB. The two two-group nonrandomized design studies [30,33] had a low RoB (final score of 7 on a 9-point scale). The three randomized controlled trials had a moderate to low RoB, with scores ranging from 7.0 [28] to 10 [32] on a 14-point scale.

Table 4: Overview of studies' risk of bias scores.

Design	Study	Positive items	Applicable items	Final score
Pretest-posttest *Maximum score 12*	Colt et al [6]	5	11	5.5
	Colt et al [31]	6	11	6.5
	Bjerrum et al [35]	6	10	7.2
	Bjerrum et al [10]	7	10	8.4
	Bjerrum et al [36]	8	10	9.6
	Gopal et al [37]	4	11	4.4
	Veaudor et al [9]	5	11	5.5
	Feng et al [34]	6	11	6.5
	Schertel et al [38]	4	11	4.4
Two-group nonrandomized *Maximum score 9*	Wahidi et al [33]	7	9	7.0
	Siow et al [30]	07	9	7.0
Randomized controlled trial *Maximum score 14*	Ost et al [28]	7	14	7.0
	Blum et al [29]	9	14	9.0
	Krogh et al [32]	10	14	10.0

The final score was calculated by dividing the number of positive items by the number of applicable items, transformed to the original maximum possible score of the risk of bias tool. Pretest-posttest study scores were transformed to a final score on a 12-point scale, two-group nonrandomized study scores were transformed to a final score on a 9-point scale, and randomized controlled trial design study scores were transformed to a final score on a 14-point scale.

Table 5 shows general features of included studies. There was a large variation in the duration of TPs, ranging from 45 min [34] in 1 day to 12 h in 12 weeks [30]. Five TPs lasted > 1 day [6,28,30,36,37]. Trainees were assessed only on the simulator in four studies [10,35,36,38]. Of the studies where an observer was (partially) included in the assessment methods, four described whether the observer was instructed on how to assess the trainees [9,31-33]. Studies that included assessment tools used a validated version of the BSTAT [33,34], a modified version of the BSTAT [30,31,37], or another validated bronchoscopy assessment tool [32].

Instructional features of included studies are described in Table 6. Apart from clinical variation (present in nine studies) and prestudy (present in 10 studies), there was no dominant pattern of any of the other instructional features.

Table 5: Overview of general features of included studies.

Study	Duration	Assessment by	Observer instruction	Validity evidence reported/referred
Colt et al [6]	> 1 d	Both	Unknown	No
Ost et al [28]	> 1 d	Observer	Unknown	No
Blum et al [29]	< 1 h and > 1 h, 1 d	Observer	Unknown	No
Wahidi et al [33]	Unknown	Observer	Yes	Yes
Colt et al [31]	> 1 h, 1 d	Observer	Yes	No
Bjerrum et al [35]	> 1 h, 1 d	Simulator	NA	Yes
Krogh et al [32]	< 1 h and > 1 h, 1 d	Observer	Yes	Yes
Bjerrum et al [10]	> 1 h, 1 d	Simulator	NA	Yes
Bjerrum et al [36]	> 1 h, 1 d, and > 1 d	Simulator	NA	Yes
Gopal et al [37]	> 1 d	Observer	Unknown	No
Veaudor et al [9]	Unknown	Both	Yes	Yes
Feng et al [34]	< 1 h, 1 d	Observer	Unknown	Yes
Schertel et al [38]	< 1 h, 1 d	Simulator	NA	No
Siow et al [30]	> 1 d	Observer	Unknown	No

NA = not applicable

Table 6: Overview of instructional features of included studies.

Study	Clinical variation	Curriculum integration	Instructor feedback	Group practice	Individualized learning	Mastery learning	Prestudy	Range in task difficulty
Colt et al [6]	Yes	No	No	No	No	No	Yes	No
Ost et al [28]	Yes	No	No	No	No	No	Yes	No
Blum et al [29]	Yes	No	No	No	No	No	No	No
Wahidi et al [33]	No	Yes	No	No	No	No	No	Yes
Colt et al [31]	Yes	No	Yes	Yes	No	No	Yes	Yes
Bjerrum et al [35]	Yes	No	Yes	No	No	No	Yes	No
Krogh et al [32]	Yes	No	No	No	No	No	Yes	Yes
Bjerrum et al [10]	Yes	No	Yes	Yes	No	No	Yes	No
Bjerrum et al [36]	Yes	No	No	No	No	No	Yes	No
Gopal et al [37]	No	No	No	No	No	No	No	No
Veaudor et al [9]	No	No	No	No	No	No	Yes	No
Feng et al [34]	No	No	No	No	No	No	Yes	No
Schertel et al [38]	No	No	Yes	No	No	No	Yes	Yes
Siow et al [30]	Yes	Yes	No	No	No	No	No	Yes

2

Table 7: Overview of outcome measures.

Outcome measure	Level	Studies, instruments
Procedure time	2	Colt et al [6]**, **Bjerrum et al [35]**, **Krogh et al [32]***, **Bjerrum et al [10]**, **Bjerrum et al [36]**, **Veaudor et al [9]**
Segments entered	2	Bjerrum et al [35], **Bjerrum et al [10]**, **Bjerrum et al [36]**, **Feng et al [34]***
Time in red-out	2	Colt et al [6], Bjerrum et al [35], **Bjerrum et al [10]**, **Bjerrum et al [36]**
Wall contacts	2	**Bjerrum et al [35]**, **Bjerrum et al [10]**, Bjerrum et al [36]
(M)BSTAT simulator	2	**Colt et al [31]***, **Gopal et al [37]***, **Feng et al [34]***
% Segments entered	2	Bjerrum et al [35], **Bjerrum et al [10]**, **Bjerrum et al [36]**
% Segments entered/min	2	**Bjerrum et al [35], Bjerrum et al [10], Bjerrum et al [36]**
Segments correctly identified	2	**Veaudor et al [9]***, **Schertel et al [38]**
Segments correctly visualized and identified / procedure time	2	**Ost et al [28]***, **Veaudor et al [9]***
Segments missed	2	**Colt et al [6]****, **Schertel et al [38]**
% time mid-lumen	2	Veaudor et al [9], Schertel et al [38]
% time scope-wall contacts	2	Veaudor et al [9], Schertel et al [38]
Procedure time	3	**Ost et al [28]***, Blum et al [29]*, Siow et al [30]*
(M)BSTAT patient	3	**Wahidi et al [33]***, **Siow et al [30]***

Studies indicated in boldface font showed a significant improvement in the listed outcome measure. (M)BSTAT = Modified Bronchoscopy Skills and Tasks Assessment Tool. *Outcome recorded via direct observation (i.e., an observer instead of simulator metrics). **Outcome both recorded via direct observation and via simulator metrics.

Table 7 shows outcome measures that were present in two or more studies. We only reported these outcome measures for clarity, given the abundance of other outcome measures that were only present once in included studies (a complete overview of all outcome measures can be found in Supplemental material 2). Eleven studies reported significant improvements in more than one-half of their outcome measures. Outcome measures were heterogeneous, ranging from simulator metrics (e.g., percentage of time in midlumen) to (validated) bronchoscopy assessment tool end scores. Two of four studies with outcomes on Kirkpatrick level 3 reported significant improvements in (modified) BSTAT outcomes [30,33]. Ost et al [28], Blum et al [29] and Siow et al [30] all reported procedure time outcomes in a patient setting. However, their effect on procedure time was conflicting.

When evaluating the study characteristics of the studies with the highest quality (mMERSQI > 12) and positive results on the most relevant outcome measures (higher than Kirkpatrick level 2), we found that these studies [30,33] shared the following characteristics: a gradual increase in task difficulty and integration of the TP in the curriculum.

Discussion

This review showed that FB SBT is an effective training method to teach basic bronchoscopy skills to novice trainees. The study quality of most studies was moderate to high. Despite these positive results, evidence for positive effects on Kirkpatrick levels 3 and 4 is still scarce. Finally, including a range in task difficulty and integrating the TP in the curriculum seem to be important to teach novices bronchoscopy skills that lead to improved bronchoscopy performance in a patient setting.

Study design

Studying the effects of FB SBT is complex: because of the nature of the intervention and for ethical reasons, designing a blinded randomized controlled trial is difficult. Therefore, most included studies used a pretest-posttest design. This design has some drawbacks, the main being a pretest effect [40], meaning that performing a pretest might influence the scores a trainee obtains on the posttest. This testing effect might have led to an overestimation of those studies' reported results. None of the studies in this review corrected for this possible pretest effect.

A review on postgraduate medical education simulation boot camps for clinical skills also reported that most studies used a single group pretest-posttest design, limiting the strength of the effectiveness of the reported interventions [41]. This was also the case in a systematic review on technology-enhanced simulation for health professions education, where most studies used a pretest-posttest design [42]. Despite its drawbacks, the pretest-posttest design may be inevitable for investigating FB SBT effectiveness, given the ethical objections associated with some trainees not practicing their skills on a simulator when one is available. However, once this design is chosen, it is important that researchers investigate the extent of a testing effect and adjust for it. In addition, to prevent bias, assessments in these studies should ideally be performed by a blinded observer.

Although long-term retention of FB skills is crucial, only one study measured participants' skills retention after training over a period of > 6 months [33]. This lack of studies measuring skill retention over a longer period of time after simulation training was also noticed in surgery and emergency care [43,44]. However, in a previous review on critical care SBT, several studies were found evaluating retention outcomes using validated assessment methods after simulation training [45]. Another study on SBT for internal medicine residents even reported both simulation retention outcomes and retention outcomes measured in a patient setting [46]. Preferably, future studies on FB SBT should measure trainees' skill acquisition longitudinally, where possible in a patient setting.

Outcome measures

Ideally, SBT leads to positive outcomes on Kirkpatrick level 4 (e.g., therapeutic/diagnostic completeness, complications, patient comfort); however, no studies in the current review reported outcomes at this level. It is difficult to design a study investigating the effect of SBT on patient outcomes from both an ethical and practical point of view, and potentially irregular links between simulation interventions and patient outcomes may exist [47,48].

There was no consensus among investigators on outcome measures: a wide variety was used, with some simulator-generated and others observer-related. Moreover, although five studies used a (modified) BSTAT, only two studies used a validated version [33,34]. In addition, all studies used a different version, leading to considerable heterogeneity, even among these studies. This problem was also identified in reviews of other areas of medical simulation training research (e.g., training for surgical skills, ophthalmology, laparoscopy, endoscopy), where included studies varied highly in outcomes and assessment methods [49-51]. To overcome this problem of heterogeneity and enable comparisons between studies, it is of great importance that future studies use validated homogeneous outcome measures, most preferably at a patient level (Kirkpatrick level 3 or 4). Patients having to undergo a bronchoscopy will be most interested in an adequately performed and complete bronchoscopy with the highest diagnostic and/

or therapeutic yield, in preferably the shortest duration possible. Therefore, assessing trainees with a previously validated qualitative assessment (e.g., validated version of the BSTAT) combined with procedure time as a secondary outcome measure will probably be very relevant to evaluate basic bronchoscopy skills. Structured progress, being the number of times an operator progressed from one segment to the correct next segment during bronchoscopy, might be added as well, because one study reported strong validity evidence of its use [52].

Instructional features

Curriculum integration and a range in task difficulty seemed to be relevant when evaluating the two studies with the highest quality [30,33]. Several bronchoscopy TPs have already incorporated SBT in their curriculum [53,54] and some fellowships in interventional pulmonology require SBT [55]. Unfortunately, no studies to date showed that curriculum integration had a positive effect on residents' functioning at a behavioral level (Kirkpatrick level 3). Together with only two studies in this review that implemented their TP in the curriculum, it seems that no well-founded conclusions about the importance of curriculum integration can be drawn. However, we regard not integrating simulation training in the curriculum as ethically questionable. Unlike the apprenticeship method, SBT allows trainees to climb the initial, steep part of the learning curve of improving their bronchoscopy skills outside the patient setting. This results in lower stress levels for the trainee and, more importantly, less patient discomfort and morbidity compared with the apprenticeship method [11,37,56], which makes mandatory SBT for all trainees ethically desirable. Laparoscopic and cardiac bedside skill TPs have implemented simulations of a range in difficulty [57], and their relevance is also in line with an earlier review investigating the effectiveness of instructional design features in SBT [58] where a positive pooled effect of simulations with a range of difficulties was reported on behavior and patient outcomes. This is in line with previous research, which showed that competence cannot be indicated solely by a high number of performed procedures [59] and where escalating task difficulty might be important to gaining competence. Nevertheless, only five studies in this review used a range of task difficulties in their program, making evidence of its relevance in an FB SBT setting rather sparse.

According to previous research, most bronchoscopy learners prefer to directly apply their newly acquired knowledge and skills [60] in practice. Therefore, simulation TPs should preferably be integrated in an experiential learning model, with case-based learning exercises and small groups with a low trainee-to-instructor ratio enabling frequent interaction and feedback [60]. However, given the sparse evidence on the actual effectiveness of these instructional features in a bronchoscopy training setting, more research into their relevance for FB SBT programs is warranted.

Strengths and limitations

This review has several strengths. It provided a comprehensive overview of current evidence on FB SBT effectiveness in improving FB skills for novice bronchoscopists. It focused solely on FB, and in contrast with previous recent research, study quality, RoB, and present instructional features were evaluated. Articles in any language were considered, and multiple databases were used for the literature search. Reviewers were blinded when they assessed study quality, general features, instructional features, and outcomes, and all assessments were performed independently.

This review also has several limitations. First, because of heterogeneity in the simulation interventions and outcome measures, no formal meta-analysis could be performed. This made it impossible to compare study outcomes quantitatively and to calculate pooled effect sizes of instructional features. Second, the number of included studies was relatively small, which limited the ability to formulate well-founded, qualitative conclusions about the relevance of instructional features. Third, studies measuring outcomes only on Kirkpatrick level 1 were excluded. Although satisfaction with the training can be important for building participants' self-confidence, this outcome measure was considered less relevant for the purpose of this review. Furthermore, we found only one Kirkpatrick level 1 study that met the inclusion criteria [61]. Fourth, the methods developed by the National Heart, Lung, and Blood Institute [22] and Tufanaru et al [21] used to calculate RoB of studies are not yet validated. Finally, it was decided to adapt the MERSQI for the purposes of this review because some parameters were found to be open to interpretation in this setting. Although this adjustment can raise questions about the validity of the MERSQI for this use, we suspect the possibility of bias to be small because these items involve at maximum only three of the 18 points that can be scored on the MERSQI.

Interpretation

SBT is effective in teaching novices basic bronchoscopy skills. Including a gradual increase in task difficulty seems to be important when designing a TP and integrating the TP into the curriculum. However, evidence for effectiveness on a behavioral (Kirkpatrick level 3) and patient level (Kirkpatrick level 4) is scarce. Future studies should therefore focus on using validated homogeneous outcome measures focused on these levels.

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Supplemental material 1: The full search strategies for studies on the effectiveness of bronchoscopy simulation training.

Database	Search
Embase	(exp bronchoscopy/ OR tracheobronchoscop*.ti,ab,kw. OR bronchial endoscop*.ti,ab,kw. OR laryngotracheobronchoscop*.ti,ab,kw. OR bronchoscop*.ti,ab,kw. OR ((bronchi.ti,ab,kw. OR bronchus.ti,ab,kw.) AND imaging.ti,ab,kw.)) AND (exp simulation training/ OR exp computer simulation/ OR computer interface*.ti,ab,kw. OR computer user interface*.ti,ab,kw. OR user computer interface*.ti,ab,kw. OR user-computer interface*.ti,ab,kw. OR simulation-training.ti,ab,kw. OR simulation-based training OR simulation-based learning OR simulation-based education OR virtual realit*.ti,ab,kw. OR ((simulat*.ti,ab,kw. or interactiv*.ti,ab,kw. or self.ti,ab,kw.) and (computer*.ti,ab,kw. or train*.ti,ab,kw. or lear*.ti,ab,kw.))) AND (competence*.ti,ab,kw. OR skill*.ti,ab,kw. OR effectiv*.ti,ab,kw. OR improve*.ti,ab,kw.)
Pubmed	((“Bronchoscopy”[Mesh] OR “Bronchi/diagnostic imaging”[Mesh] OR bronchoscop*[tiab]) AND (“Simulation Training”[Mesh] OR “Computer Simulation”[Mesh] OR “User-Computer Interface”[Mesh] OR virtual realit*[tiab] OR ((simulat*[tiab] OR interactiv*[tiab] OR self[tiab]) AND (computer*[tiab] OR train*[tiab] OR lear*[tiab])))) AND (“Clinical Competence”[Mesh] OR competence*[tiab] OR skill[tiab] OR effectiv*[tiab] OR improve*[tiab])
Web of Science	TS=((bronchoscop* OR tracheobronchoscop* OR “bronchial endoscop*” OR laryngotracheobronchoscop* OR ((bronchi* OR bronchus*) AND imag*)) AND (“simulation training” OR “computer simulation*” OR “computer interface*” OR “computer user interface*” OR “user computer interface*” OR “user-computer interface*” OR simulation-training OR “simulation-based training” OR “simulation-based learning” OR “simulation-based education” OR “virtual realit*” OR ((simulat* OR interactive* OR self*) AND (computer* or train* or lear*))) AND (competence* or skill* or effectiv* or improve*))
Scopus	TITLE-ABS-KEY((bronchoscop* OR tracheobronchoscop* OR “bronchial endoscop*” OR laryngotracheobronchoscop* OR ((bronchi* OR bronchus*) AND imag*)) AND (“simulation training” OR “computer simulation*” OR “computer interface*” OR “computer user interface*” OR “user computer interface*” OR “user-computer interface*” OR simulation-training OR “simulation-based training” OR “simulation-based learning” OR “simulation-based education” OR “virtual realit*” OR ((simulat* OR interactive* OR self*) AND (computer* or train* or lear*))) AND (competence* or skill* or effectiv* or improve*))

Supplemental material 2: Full overview of outcome measures of included studies

Study	Outcomes
Colt 2001	VR simulator - Procedure time - **Number of wall contacts/minute bronchoscopy** - % time in red-out - **Segments missed** Inanimate model - Procedure time - **Segments missed**
Ost 2001	Patient bronchoscopy - **Procedure time** - Number of segments entered - Number of segments correctly identified - **% of segments visualized and correctly identified/time in seconds** - **Qualitative bronchoscopy nurse score** - Lidocaine used, ml - Coughing episodes - **Meperidine used, mg**
Blum 2004	Patient bronchoscopy - Procedure time - **Number of verbal assists** - **Number of physical assists** - Incidence of redundant lobar exams - **Thoroughness of exam** - Confidence - Proficiency
Wahidi 2010*	Patient bronchoscopy BSTAT at **5th**, **10th**, **15th**, **20th**, **30th**, **50th**, 75th and **100th** bronchoscopy
Colt 2011*	Low-fidelity airway model - **Cognitive skill test** - **mBSTAT**
Bjerrum 2013*	Virtual reality simulator - **% of segments entered/minute** - Red-out in seconds - **Number of wall collisions** - **Procedure time** - % of segments entered
Krogh 2013*	Virtual reality simulator - **Bronchoscopy quality score** - **Procedure time** - Checklist-score
Bjerrum 2014*	Virtual reality simulator - **% of segments entered/minute** - **Red-out in seconds** - **Number of wall collisions** - **Procedure time** - **% of segments entered**

Supplemental material 2: Full overview of outcome measures of included studies *(continued)*

Study	Outcomes
Bjerrum 2016*	Virtual reality simulator - **% of segments entered/minute** - **Red-out in seconds** - Number of wall collisions - **Procedure time** - **% of segments entered**
Gopal 2018*	Virtual reality simulator - **mBSTAT (anatomy part)** - **mBSTAT (bronchoscopy skills part)**
Veaudor 2018*	Virtual reality simulator - **Visualized anatomical structures** - **Correctly identified anatomical structures** - **Procedure time** - **% of segments correctly visualized and identified/time in seconds** - % of time with scope-wall contact - % of time with scope at mid-lumen
Feng 2020*	Low-fidelity airway model - **mBSTAT** - **Proportion of students able to successfully navigate to and enter target segment**
Schertel 2021*	Virtual reality simulator - **Segments correctly identified on 1st attempt** - **Segments correctly identified on any attempt** - **Segments skipped** - % of time in mid-lumen - % of time with scope wall-contact
Siow 2021*	Patient bronchoscopy - **BSTAT score 6 weeks** - **BSTAT score 21 weeks** - **Airway anesthesia score 6 weeks** - **Airway anesthesia score 12 weeks** - Procedure time - Vocal cord anesthesia time - Intubation attempts

Outcome measures (self-reported outcome measures not included) indicated in bold were significantly improved after the simulation intervention. * = the majority of the reported outcome measures in the study were significantly improved after the intervention.

Chapter 3

The influence of the pretest effect on posttest scores in a bronchoscopy simulation setting

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Abstract

Introduction: Bronchoscopy simulation studies often use a pretest-posttest design. This design may lead to a pretest effect, exaggerating intervention outcomes. We evaluated this effect on common bronchoscopy simulation outcome measures.

Methods: Twenty medical trainees lacking bronchoscopy experience performed two simulator tasks in a pretest and posttest session with a 4-6 hour break in between. The tasks assessed participants' navigational skills in either a non-anatomical environment (NAE) or an anatomical environment (AE). NAE outcome measures were simulator metrics related to time and accuracy. AE outcome measures were procedure time, number of correctly entered airway segments and overall scores on a previously validated assessment tool, adapted to the simulation procedure.

Results: A significant pretesting effect was observed for procedure time in both tasks (NAE: 57 ± 15 seconds pre versus 38 ± 12 seconds post, P<.001; AE: 5.3 ± 1.3 minutes pre versus 4.4 ± 1.0 minutes post, P<.001). In the NAE, the number of wall contacts reduced 40% in the posttest (P<.001), but the number of wall contacts per minute of procedure time did not improve (5.1 ± 2.6 pre versus 5.0 ± 2.3 post, P=0.8). Overall assessment tool scores in the AE also did not improve (pre 2.0[1.0], post 2.0[0.0], P=0.4).

Conclusions: A significant pretest effect was observed for procedure time in both simulated environments, but not for outcome measures assessing navigational skills (i.e. number of wall contacts/minute and assessment tool scores). Future pretest-posttest bronchoscopy simulation studies should consider these findings.

Introduction

A pretest-posttest design is commonly used in studies to measure the effect of a training intervention on skill acquisition of trainees. In a pretest-posttest design, participants perform a test before and after a training intervention and the observed difference between participants' performance scores between the two tests provides an indication of the improvement, which is often reported as the training effect. This is a feasible design when randomizing participants would be unethical or impractical. However, a major drawback of this design is that posttest results might be (partially) influenced by several other factors than the intervention, such as maturation, history and the pretest itself [1,2]. This last phenomenon of posttest scores being (partially) dependent on pretest results, is referred to as the pretest effect [3]. When it comes to bronchoscopy simulation studies, the pretest-posttest design is often chosen [4], because adopting a randomized controlled trial design herein would inevitably lead to ethical concerns, since 'control' trainees would have to practice their initial bronchoscopy skills on patients. Furthermore, due to the nature of the intervention, designing a blinded trial will raise serious practical issues when executing the study. To our knowledge, however, no bronchoscopy simulation studies so far have investigated the possibility of a pretest effect, let alone corrected for it. The reported training effect in pretest-posttest bronchoscopy studies may therefore not be solely attributable to the intervention but could also be partially influenced by the pretest. If such an influence exists, the magnitude of the actual intervention effect could be decreased. Therefore, the main aim of this study was to determine the magnitude of this pretest effect on several commonly used bronchoscopy outcome measures in a bronchoscopy simulation setting.

Materials and methods

Participants and setting

Twenty Dutch medical trainees were invited to voluntarily participate in this pretest-posttest study through printed advertisements handed out on campus. This participant number was partially based on participant numbers observed in previous bronchoscopy simulation studies investigating the suitability of outcome measures [5,6], however, we intentionally expanded it slightly to improve robustness and reliability. Participants had to be between 18 and 35 years old and had to lack any bronchoscopy experience. The first author scheduled the study sessions in consultation with participants who gave their written consent, on days and times convenient for all parties. Students who participated in the study were given a 20 euro voucher that could be used at an online store. The study was conducted at the simulation center of the Maastricht University Medical Center+, from November 2021 to October 2022.

Ethics and Consent

This study was reviewed and approved on 15-03-2021 by the Ethical review committee of the University of Twente, with the approval number: 210232. All medical trainees provided written informed consent to participate in the study and for study publication. This study was carried out in accordance with the Declaration of Helsinki.

Simulator

The simulator used was the GI-BRONCH Mentor flexible bronchoscopy simulator (Surgical Science, Sweden).

Procedure

First, a pretest session took place, consisting of a short introduction (see Word document, Supplemental material 1) into bronchoscopy and an explanation of safe handling of the simulator equipment by the first author, followed by the pretest. The pretest consisted of two simulator tasks where the participant had to navigate the scope in a non-anatomical ('basic scope manipulation') and an anatomical environment ('lung anatomy and bronchial segments') (Figure 1A and 1B). To prevent muscle fatigue, a short break was scheduled in between the two simulator tasks. During this break, the first author provided some basic background information using an anatomy poster [7]. Notably, the information shared was calibrated to ensure participants could not independently navigate the bronchial tree without further assistance (see Word document, Supplemental material 2). Following the pretest session, a substantial break of 4-6 hours was scheduled, after which a posttest session took place, where participants performed the same two simulator tasks.

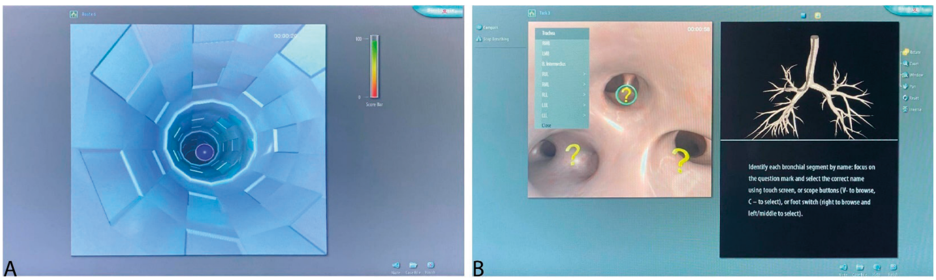

Figure 1: The basic scope manipulation task (1A) and the lung anatomy and bronchial segments task (1B) on the GI-BRONCH Mentor flexible bronchoscopy simulator.

Simulator tasks

In the non-anatomical environment (NAE) or basic scope manipulation task, participants were tasked with following a blue ball through a digital maze by navigating the tip of the bronchoscope correctly. Participants performed 5 runs of this task during both the pretest and posttest, but they were allowed to do one practice run before the pretest. The simulator had 8 different trajectories that were randomly chosen for each run. No knowledge regarding anatomy was required, since the different trajectories did not reflect bronchial anatomy.

In the anatomical environment (AE) or the lung anatomy and bronchial segments task, the goal was to navigate to and enter all airway segments in a specific order, sequentially from segment 1 to 10. In this task, question marks appeared in each airway segment and turned green when the trainee had sufficiently visualized the segment, while keeping the scope stable in the same position for a few seconds. A segment is counted as correctly entered if the participant can reach the question mark and does not have to try multiple times to turn the question mark into green due to weak navigational skills. To facilitate comprehension, the first author demonstrated the task shortly, by navigating to the different lobes and pointing out the segments and question marks that were visible upon entering the lobe. As the participants, due to their lack of bronchoscopy experience, had no knowledge of the anatomy of the bronchial tree, it was deemed necessary for the first author to provide instructions where to navigate to, after which the participant had to try to turn the question mark in each segment (segments 1-10 in both lungs) into green by navigating the tip of the bronchoscope in a correct way to this segment. The first author did not provide any other additional instructions during the study session.

Outcome measures

Adequate bronchoscopy performance can be seen as a function of the operator's ability to navigate the tip of the bronchoscope, albeit in an NAE or AE, in an orderly manner. This entails keeping the tip of the bronchoscope as much as possible in the center of the 'tube' (in a NAE) or bronchus (AE) while minimizing the number of wall collisions and being able to enter all lung segments (AE). This aspect could be regarded as one's 'navigational skills' in scope handling. In real life and for patients' convenience this should, ideally, be done as quickly as possible.

For the first task (navigation in the NAE), outcome measures were the 5-run average posttest pretest differences in the four simulator metrics that appeared on the screen after each run: 1) total time, 2) % of time at mid-lumen, 3) % of time with scope-wall contact and 4) the total number of wall contacts. Previous research has demonstrated that these outcome measures can correlate with bronchoscopist skill levels [6].

Additionally, if the procedure takes longer, the chance of having a higher number wall contacts will increase proportionally. Therefore, the number of wall contacts per minute of procedure time was added as well as an extra outcome measure for evaluating navigational skills for this task.

For the second task (navigation in an AE), outcome measures were posttest pretest differences in 1) procedure time, and in order to assess navigational skills: 2) number of correctly entered segments and 3) overall scores on a previously validated bronchoscopy assessment tool [8], adapted to the simulation procedure (see Word document, Supplemental material 3), filled in by a trained observer (Eveline Gerretsen). The tool consists of seven parameters, leading to a composite overall score on a 5-point scale.

Statistical Analysis

Data were analyzed using SPSS, version 26. Given their normal distributions, paired t-tests were used to compare pretest and posttest outcome measures of the basic scope manipulation task, procedure time for both tasks and the number of correctly entered segments in the lung anatomy and bronchial segments task. Bonferroni correction resulted in a corrected threshold of $\alpha = 0.01$ for the NAE and $\alpha = 0.017$ for the AE. For comparison of assessment tool end scores, the nonparametric Wilcoxon signed rank test was used, with a significance threshold of $\alpha = 0.05$. Effect sizes were calculated using Cohen's d, a commonly used measure for quantifying the magnitude of effect sizes in medical education studies [9], where values of 0.2, 0.5, and 0.8 respectively indicate small, moderate, and large effect sizes.

Results

20 medical trainees participated in the study, 16 of them being women. Mean age was 23.9 years with a standard deviation of 2.9 (range 18-32).

Non-anatomical environment

Pretest and posttest results for all simulator metrics in the NAE are described in Table 1. A significant difference between the posttest and pretest was observed for total time and the number of wall contacts (both $p < 0.001$, Cohen's d = -1.8 and -0.9 respectively), suggesting a large pretest effect. Figure 2 shows total time means and standard deviations and wall contacts per minute means and standard deviations. In contrast to total time, no significant difference ($P=0.8$) was observed between the pretest and posttest for the number of wall contacts per minute of procedure time. Finally, there was also no significant difference observed for the % of time at mid-lumen and the % of time with scope-wall contact.

Table 1: Basic scope manipulation simulator metrics, average of 5 runs.

Outcome measure	t (df)	Pretest mean ± SD	Posttest mean ± SD	P-value	Cohen's *d*
total time (seconds)	-8.0 (19)	57.4 ± 15.1	38.3 ± 11.6	<0.001*	-1.8
percentage of time at mid-lumen	1.5 (19)	53.7 ± 13.0	56.3 ± 9.3	0.1	0.3
percentage of time with scope-wall contact	-1.4 (19)	14.0 ± 7.8	12.2 ± 6.6	0.2	-0.3
number of wall contacts	-4.3 (19)	4.8 ± 2.6	2.9 ± 1.1	<0.001*	-0.9
number of wall contacts per minute of procedure time	-0.3 (19)	5.1 ± 2.6	5.0 ± 2.3	0.8	-0.06

Paired samples t-test. * = statistically significant. df = degrees of freedom.

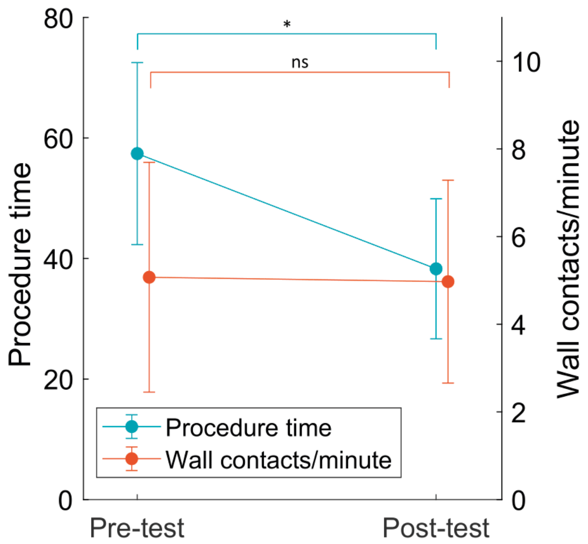

Figure 2: Mean procedure time and mean number of wall contacts per minute of procedure time and their standard deviations for the basic scope manipulation *task*. * = P<0.001; NS = not significant.

Anatomical environment

For the AE outcome measures, no improvement in the scores on the assessment tool was found (pretest 2.0 (IQR 1.0), posttest 2.0 (IQR 0.0), P=0.4). The number of correctly entered segments (Table 2) between the posttest and pretest did not improve significantly either. In contrast to the total number of correctly entered segments, procedure time did improve significantly (pretest 5.3 ± 1.3 minutes vs posttest 4.4 ± 1.0 minutes, t(19) = -4.9, $p < 0.001$; Figure 3). Effect size (Cohen's d) for procedure time was -1.1, indicating a large pretest effect.

Table 2: Correctly entered segments in the lung anatomy and bronchial segments task.

Outcome measure	t (df)	Pretest mean ± SD	Posttest mean ± SD	P-value	Cohen's *d*
Entered segments right lung (max = 10)	1.6 (19)	5.6 ± 1.8	6.2 ± 1.1	0.1	0.3
Entered segments left lung (max = 8)	1.6 (19)	5.0 ± 1.3	5.3 ± 1.0	0.1	0.4

Paired samples t-test. df = degrees of freedom.

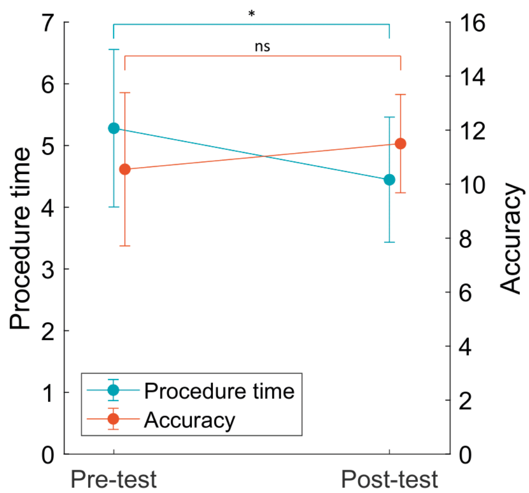

Figure 3: Mean procedure time and accuracy (the total number of correctly entered segments) and their standard deviations for the lung anatomy and bronchial segments task. Legend: * = P<0.001; NS = not significant.

Discussion

This is to our knowledge the first study evaluating a possible pretest effect in a bronchoscopy simulation setting. A significant and large pretest effect was found for procedure time in a bronchoscopy simulation setting among medical trainees. In the non-anatomical environment, a significant pretest effect was observed for the number of wall contacts. However, when corrected for procedure time this effect was no longer apparent, indicating no real improvement in navigational skills. This was also confirmed by the observation that no pretest effect was found for the outcome measures '% of time at mid-lumen' and the '% of time with scope-wall contact'. In a more realistic anatomical environment, no significant pretest effect was observed for the number of correctly entered segments and overall bronchoscopy competence either, also indicating that no pretest effect was observed in navigational skills.

Bronchoscopy simulation training studies use a wide range of parameters to measure participant bronchoscopy competence, ranging from assessment tool scores, number of entered and/or correctly identified segments to simulator-generated metrics such as the percentage of time in mid-lumen and the number of wall contacts to procedure time [4]. Many of these studies use a pretest-posttest design for practical and ethical reasons. The results of this study showed a large pretest effect for two outcome measures that are commonly used in bronchoscopy simulation studies: procedure time and the number of wall contacts. However, this effect was not seen in those outcome measures more related to actual navigational skills or dexterity (in a NAE: % of time at mid-lumen, the % of time with scope-wall contact and number of wall contacts/ procedure time and in a AE: number of correctly entered segments and assessment scores) Therefore, the only parameters for which there appears to be an actual pretest effect are procedure time and total number of wall contacts; no such effect appears to be there at play outcome measures related to navigational skills.

The pretest posttest design is also a common design in other medical simulation studies. Previous systematic reviews on postgraduate medical education simulation "boot camps" for clinical skills, resuscitation simulation training, and technology-enhanced simulation for health professions education also reported that most studies used a single group pretest-posttest design [10-12]. The continuing shift from the traditional apprenticeship model, "see one, do one, teach one" towards simulation-based training [13-15] and practical and ethical issues with other study designs will most probably lead to a growing number of simulation studies with a pretest-posttest design. The demonstrated pretest effect for procedure time and wall contacts in our study underscores the importance of future pretest-posttest studies refraining from solely using these parameters as major outcome measures. These studies should also use a measure to evaluate navigational skills, such as the number of wall contacts per minute and/or validated performance quality assessment tool end scores. Failing to do so might lead to a too optimistic view of training intervention effects in these studies. Moreover, emerging evidence suggests that novice bronchoscopists can attain simulator scores on bronchoscopy simulators comparable to those of experienced bronchoscopists, making a compelling case for the adoption of assessment tools with robust validity evidence for the assessment of bronchoscopy trainees' competences [16,17].

Strengths and limitations

To our knowledge, this was the first study that demonstrated a large pretest effect for procedure time and the number of wall contacts in the context of bronchoscopy simulation. We believe that these findings can serve as a compelling prompt for awareness among researchers working with pretest-posttest designs, making them aware of the significant pretest effect on procedure time and wall contacts and encouraging them to incorporate validated navigational skills/dexterity measures as well to investigate intervention effects. In addition, the majority of outcome measures (i.e. all simulator metrics for the AE [basic scope manipulation] task and procedure time and the number of correctly entered segments for the AE [lung anatomy and bronchial segments] task) were measured in an objective way decreasing the possibility of observer biases.

Despite these strengths, the study also has several limitations. First, the participants, who were medical trainees without any bronchoscopy knowledge or experience, may not fully represent the intended target population of bronchoscopy simulation training programs, i.e., residents working in the pulmonology field. However, the most substantial pretest effects are expected to occur in untrained populations, given the steep ascent of the learning curve of acquiring bronchoscopy skills [18]. Therefore, it is not expected that larger pretest effects with regards to bronchoscopic navigational skills will be demonstrated in other, more representative populations. It might be worthwhile, however, for future studies to investigate the extent of a pretest effect with regards to procedure time in these populations. Second, the small sample size (n = 20) and lack of follow-up data limit the generalizability of the findings and the ability to assess the stability of the pretest effect over time. Future studies with larger sample sizes and follow-up assessments could help to assess whether the observed pretest effect for procedure time and the number of wall contacts persists. Third, the first author performed the full data collection as the study sessions took place at office hours on workdays and scheduling these sessions during these times with a pulmonologist with experience in assessing bronchoscopy trainees would be rather difficult from a practical point of view. Although the first author had already gained extensive experience with use of the assessment tool, a possible observer bias cannot be entirely ruled out. Nevertheless, given the number of correctly entered segments in this task and the simulator metrics of the navigation task were measured in an objective way and no improvements apart from procedure time were demonstrated there, we think that the main findings for this study (a large pretest effect on procedure time but not on navigational skills) remain unaffected by this possible bias.

Conclusions

This study demonstrated a significant pretest effect for medical trainees on procedure time and number of wall contacts in a bronchoscopy simulation setting. However, this effect was not observed for other commonly used bronchoscopy simulation outcome measures, being the % of time at mid lumen, number of wall contacts per minute of bronchoscopy, number of correctly entered segments and bronchoscopy assessment scores. Therefore, these outcome measures are preferable for use in future studies.

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Supplemental material 1: Introduction bronchoscopy and simulator equipment

Welcome to this study session, thank you very much for taking the time to participate. I will now first provide an explanation of the purposes of a bronchoscopy and explain how to handle the simulation equipment safely. A bronchoscopy is a procedure where a doctor inspects the airways or takes biopsies from the airway wall by inserting a camera through the patient's nose or mouth, via the trachea. In this study, you will perform a bronchoscopy on a simulator. The bronchoscope of the simulator is almost identical to a regular bronchoscope used in the hospital. It is important to know that you must handle the bronchoscope very carefully and avoid the tip hitting any objects. Do you have any questions so far?

Supplemental material 2: Background information lung anatomy

This poster is a schematic representation of the lungs. As you can see, the right lung consists of 3 lobes, the upper, middle and lower lobe, and the left lung consists of 2 lobes, the upper and lower lobe. The segments of both lungs are numbered from 1 – 10, although for the left lung segment 1 and 2 are joined and segment 7 misses. In the next task, you are asked to navigate to and enter all segments, but given your lack of anatomy background knowledge, I will instruct you first where the segments are situated, after which you can try to enter them. Do you have any questions?

Supplemental material 3: Basic bronchoscopy assessment tool

Bronchomotor skills

1. Scope introduction
   A. In 1 try
   B. In 2 tries
   C. In 3 or more tries

2. Right lung
   A. All segments entered correctly
   B. 1 segment not entered correctly: segment ___
   C. 2 or more segments not entered correctly: segments ___

3. Left lung
   A. All segments entered correctly
   B. 1 segment not entered correctly: segment ___
   C. 2 or more segments not entered correctly: segments ___

4. Intra-bronchial scope movement overall
   A. No unnecessary wall contacts, good centralization of the scope
   B.
   C. Moderate amount of wall contacts, moderate centralization of the scope
   D.
   E. Many wall contacts, bad centralization of the scope

5. Scope handling
   A. No unnecessary movements in the horizontal plane
   B.
   C. Moderate amount of unnecessary movements in the horizontal plane
   D.
   E. Many unnecessary movements in the horizontal plane

6. Hand-wrist movements
   A. Right position of hand and fingers during the procedure with a relaxed posture
   B.
   C. Right position of hand and fingers during the procedure with too much tension
   D.
   E. Wrong position of hand and fingers during the procedure with too much tension

7. Procedure time:_______

Overall rating

A. Very good
B. Good
C. Average
D. Bad
E. Very bad

Chapter 4

Development and Validation of two Bronchoscopy Knowledge Assessments

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Abstract

Introduction: Simulation-based training (SBT) is a key method for teaching bronchoscopy skills to pulmonology residents. A theoretical foundation can enhance SBT efficiency. This study developed and evaluated the validity of an anatomy and theoretical bronchoscopy exam using Kane's validity framework.

Methods: 19 anatomy and 58 theoretical exam questions, developed by pulmonology experts, were assessed through two Delphi rounds. Both exams were then taken by 53 prepared pulmonology residents. The theoretical exam was also taken by three unprepared groups: novices, intermediates and experts. Using the residents' data, scoring evidence for the theoretical exam was evaluated using item difficulty and item discrimination indices, and generalization evidence was assessed using Cronbach's alpha. Extrapolation evidence was obtained by comparing theoretical exam scores across the different groups. Implications evidence for both exams was gathered by evaluating residents' preparedness, based on exam performance and instructor feedback.

Results: The Delphi procedure resulted in 19 anatomy and 31 theoretical questions. Item difficulty values predominantly ranged from 0.85-1.0, item discrimination indices mostly ranged from 0.0-0.25. Cronbach's alpha was 0.55. While scores appeared to correlate with experience, no significant differences were observed between the four groups. Most residents passed both exams on their first attempt, and instructors rated their anatomical knowledge as good.

Conclusion: Expert involvement and acceptable item difficulty, item discrimination and internal consistency supported the exams' validity. The exams also effectively motivated residents to prepare for SBT. These findings highlight the value of pre-SBT exams in enhancing residents' preparation, allowing more time to focus on mastering procedural skills.

Introduction

Over the past two decades, simulation-based training has increasingly been employed to teach flexible bronchoscopy skills to pulmonology trainees [1]. This approach allows trainees to practice procedural skills without compromising patient safety, making it a desirable training alternative to the traditional apprenticeship model. However, while simulation-based training is effective for developing practical skills, it does not provide trainees with a comprehensive understanding of knowledge such as topical anesthesia, sedation, anatomy, complications and (contra-)indications for the procedure. Recognizing this limitation, pulmonology educators have emphasized that a theoretical stage in bronchoscopy training should precede simulation-based training [2]. Pre-existing knowledge in general, and especially anatomical knowledge of the bronchial tree, can potentially enhance the efficiency of simulation-based training by reducing the time spent on theoretical instruction and explanation of anatomy, allowing trainees to focus more effectively on mastering procedural skills.

Basic knowledge relevant for bronchoscopy training is typically assessed through written examinations. Despite the recognized importance of these assessments, few validation studies have been conducted on theoretical bronchoscopy exams [3-5]. Moreover, these studies have significant limitations: one, conducted 16 years ago [3], may no longer fully reflect current clinical practices, while the others provided limited validity evidence, relying solely on expert consensus for item development [4], and another conducted item analysis on a sample of only seven participants [5]. These limitations highlight the need for a more rigorous validation process of knowledge assessments. In assessment, validity is not simply about whether a test accurately measures a specific construct, but rather about the strength of the evidence supporting the interpretations and uses of exam scores [6]. Comprehensive validity assessment requires triangulating evidence from several sources [7]. In this study, we will use Kane's validity framework, which emphasizes that validity is a chain of inferences, each requiring evidence to be collected [6]. These inferences include *scoring*, referring to the appropriateness of scoring criteria, *generalization*, concerning the generalizability of the test scores to the broader domain, *extrapolation*, concerning the meaning of the test score for real-life performance and *implications*, concerning the use of the test scores to make decisions about learners [8].

In summary, there is a scarcity of validity evidence for exams assessing the knowledge required for bronchoscopy performance. This study examined the validity of an anatomy and a theoretical exam in bronchoscopy, gathering evidence for the *scoring*, *generalization, extrapolation* and *implications* inferences. As such, this study intended to provide valuable insights for future development and refinement of knowledge assessments for pulmonology residents.

Methods

Context

In 2020, a mandatory simulation-based training program for novice Dutch pulmonology residents was introduced [9]. To ensure that residents were adequately prepared, two exams were implemented as prerequisites for participation in the training program. These exams were developed by a panel of six Dutch pulmonology experts. The first exam, hereafter referred to as the 'anatomy exam' for clarity, focused exclusively on anatomy. A 100% score was required to ensure that residents entering the simulation-based bronchoscopy training had adequate anatomical knowledge of the bronchial tree, so that no valuable training time would be wasted on explaining anatomy. The second exam, hereafter referred to as the 'theoretical exam', was based on the British Thoracic Society (BTS) guideline [10]. This exam evaluated broader bronchoscopy-related knowledge, including topical anesthesia, sedation, pre-procedure preparations, (contra-)indications for bronchoscopy, monitoring, complications, staff and hygiene protocols, and sampling techniques. Trainees were required to answer 60% of the questions correctly on the theoretical exam. Since the most important requirement was that residents had a solid understanding of anatomical knowledge before entering the simulation-based training program, broader bronchoscopy-related knowledge was considered less critical for admission. These entry requirements aimed to ensure that residents prepared thoroughly, entering the simulation-based training with a solid knowledge base.

Development of the exams

The initial anatomy and theoretical exam, developed by the Dutch pulmonology experts, contained 19 and 58 multiple choice questions, respectively. These questions were then reviewed by a test expert (HP), who identified issues related to clarity, phrasing and question structure. Questions were refined to ensure they were unambiguous and well-structured. Next, two Delphi rounds were conducted with five European pulmonology experts (PC, LC, DG, BH, MM). In each round, the experts rated the relevance of each question using a 5-point Likert scale and provided feedback where necessary. A question was considered relevant if at least four experts rated it as 4 or 5 out of 5. During the first Delphi round, all 19 anatomy questions and 20 theoretical questions were consistently rated as relevant by the experts and were directly included in the final question sets. The remaining 38 theoretical questions were judged by the researchers, who determined that three questions were ambiguous and had to be discarded. The remaining 35 theoretical questions were re-evaluated in a second Delphi round. Following this second review, 11 additional theoretical questions were deemed relevant. Ultimately, this process resulted in the inclusion of 19 questions in the anatomy exam and 31 questions in the theoretical exam. One example question from each exam is provided in Supplemental Material 1 to illustrate the structure and content of the items.

Participants and data collection

The anatomy and theoretical exams were taken by Dutch pulmonology residents (n = 53), hereafter referred to as 'residents' for clarity, who were required to pass both before being allowed to attend the simulation-based training. The residents were instructed to study material related to bronchoscopy [10-13].

The theoretical exam was also administered to three additional groups of participants who were explicitly instructed not to prepare for the test: 1) medical residents without any bronchoscopy experience (novices; n = 15), 2) pulmonology residents who started their residency before 2020 and, therefore, did not have to attend the mandatory simulation-based training program and had performed 5–100 bronchoscopies (intermediates; n = 13) and 3) pulmonologists who had performed more than 500 bronchoscopies (experts; n = 14). Only the theoretical exam was administered to these groups, as the anatomy exam was deemed irrelevant: novices, having no anatomical knowledge, would achieve scores close to 0%, while those regularly performing bronchoscopies would be expected to score near 100%. Consequently, no additional *scoring*, *generalization*, or *extrapolation* evidence was collected for the anatomy exam, as no meaningful differences were expected. Instead, only *implications* evidence was collected for the anatomy exam. Table 1 shows demographics of all participant groups. Participants provided written informed consent before receiving a link to the online exam environment via email, which allowed them to complete the exams at their convenience. Due to logistical constraints, no formal testing conditions, supervision, or remote proctoring were implemented. Both exams were administered through the online testing platform *Remindo* (version 22.5 to 24.4) and responses were collected between October 2022 and October 2024. The anatomy exam consisted of 19 questions, from which 10 were randomly selected for each resident. A passing score of 100% was required. In case of a retake, a new set of 10 questions was randomly selected from the original 19. The theoretical exam, which covered all 31 questions, required a passing score of 60%. Residents retaking the theoretical exam were presented with the same 31 questions as in their initial attempt. To minimize the possibility of extensive searching by the participants, the time to complete each exam was limited to 1 h. For all other participant groups, only data from those completing the theoretical exam within this one-hour timeframe on their first attempt were included in the analysis. The dataset contained no personally identifiable information; researchers could only access participants' experience levels, responses to the questions and their final scores. This study was approved by the Ethics Committee of the University of Twente (approval number 210232).

Table 1: Participant demographics

Group	*N*	Age (mean±SD)	Male, *n* (%)	Female, *n* (%)
Novices*	15	28.0 (±3.1)	6 (40)	9 (60)
Intermediates**	13	31.2 (±3.4)	6 (46)	7 (54)
Experts***	14	42.3 (±8.2)	8 (57)	6 (43)
Residents****	53	30.9 (±2.9)	18 (34)	35 (66)

* = non-pulmonology residents without any bronchoscopy experience, ** = pulmonology residents who started their residency before 2020, had performed 5–100 bronchoscopies, and did not have to attend the mandatory simulation-based training program, *** = pulmonologists who had performed more than 500 bronchoscopies, **** = pulmonology residents who had to attend the mandatory simulation-based training program and were required to pass both the anatomy and theoretical exam.

Scoring evidence

To evaluate item quality of the theoretical exam, item difficulty and item discrimination were calculated using the data of the residents who prepared for the exam, considering only their first attempt. Item difficulty was determined by calculating the percentage of residents who answered each item correctly; a lower value may indicate a higher difficulty for that item. Item discrimination was analyzed by ranking residents based on their final scores. Following the methodology of similar studies [14,15], the resident data were divided into three groups: the 17 residents with the lowest scores, the 19 residents with the middle scores and the 17 residents with the highest scores. The discrimination index for each item was calculated as the difference in the proportion of correct answers between the high- and low-scoring groups, indicating how well each question differentiated between stronger and weaker performers. A higher discrimination index indicates that the item more effectively distinguishes between high- and low-performing individuals. All analyses were conducted in RStudio, R version 4.4.1.

Generalization evidence

Internal consistency of the theoretical exam, using the data of the residents who prepared for the exam and considering only their first attempt, was assessed primarily using Cronbach's alpha, calculated with the Pysch package in R. Values closer to 1.0 indicate strong internal consistency, meaning that exam items are highly correlated and measure a similar underlying concept. However, in a highly homogeneous group with little variance in exam scores, internal consistency may decrease because the items lose their ability to differentiate between examinees, reducing the overall covariance between items. Therefore, alternative reliability metrics were also calculated as supplementary analyses: split-half reliability, using the Spearman-Brown formula, and McDonald's omega total.

Extrapolation evidence

Theoretical exam scores, considering only participants' first attempts, were compared across the four participant groups using the Kruskal-Wallis test in RStudio. Post-hoc pairwise comparisons were performed with Bonferroni adjustments to account for multiple comparisons. The effect size for the overall group difference was estimated using Epsilon squared (ε^2) [16]. Additionally, a Spearman's rank-order correlation was performed to examine the relationship between bronchoscopy experience level (novice, intermediate, expert) and theoretical exam scores.

Implications evidence

The most important objective was to ensure that, before starting the simulation-based bronchoscopy training, residents would have acquired adequate anatomical knowledge of the bronchial tree. The training program began with a brief 15-minute recap of bronchial anatomy by the trainer, intended as a refresher rather than instruction. As residents were required to achieve a perfect score on the exam prior to participation, we recorded how many attempts were needed to pass the anatomy exam, as this may provide insight into how thoroughly residents prepared for the exam. We also administered a questionnaire to the instructors of the simulation-based training, asking them to 1) rate how well-prepared residents were on average regarding anatomical knowledge, on a Likert scale from 1 to 5, with higher ratings indicating greater preparedness, and 2) indicate how much additional time, on average, was needed to explain anatomy during the training, beyond the initial recap. This was rated on a scale where 1 = 0 minutes, 2 = 15 minutes, 3 = 30 minutes, 4 = 1 hour and 5 = 2 additional hours. Furthermore, to gather evidence for the *implications* inference of the theoretical exam, we compared the proportion of residents who prepared for the exam and passed on their first attempt with the proportions of the participants in the other unprepared groups.

Results

Scoring evidence

Based on the data of the residents who prepared for the exam (n = 53), item difficulty values for the theoretical exam varied from 0.3 to 1.0, with a notable peak in the 0.85-1.0 range, shown in Fig. 1). The item discrimination indices ranged from -0.23 to 0.59, with the distribution peaking in the 0.0 – 0.25 range (shown in Fig. 2).

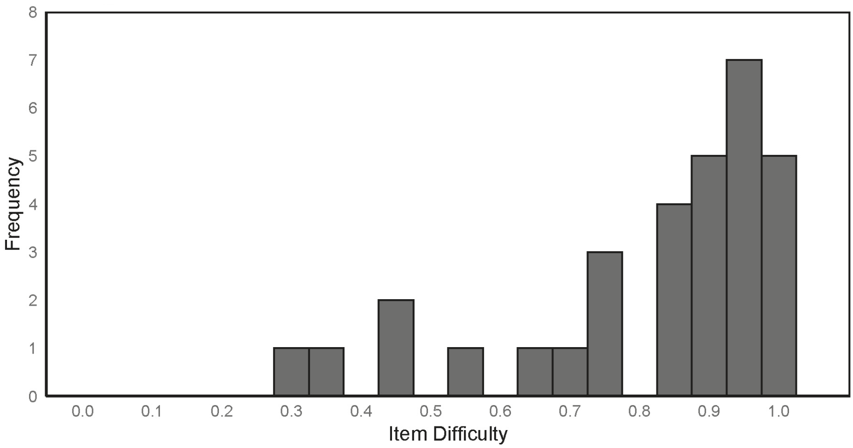

Figure 1: Distribution of item difficulty indices for the theoretical exam (a higher score indicating an 'easier' question), based on the exam results of the residents (n = 53). The Y-axis represents the number of questions.

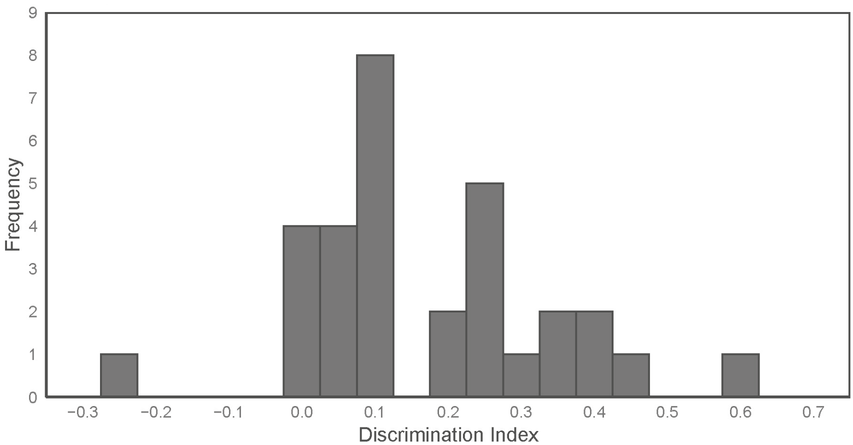

Figure 2: Distribution of item discrimination indices for the theoretical exam (with a higher index indicating a better discrimination ability between 'high' and 'low' performing participants), based on the exam results of the residents (n = 53). The Y-axis represents the number of questions.

Generalization evidence

The internal consistency of the theoretical exam, assessed using Cronbach's alpha of the data of the residents who prepared for the exam, was 0.55. Supplementary analyses showed a Spearman-Brown corrected split-half reliability of 0.61 and McDonald's omega total of 0.76.

Extrapolation evidence

A comparison of performance on the theoretical exam across the four participant groups revealed a significant difference (Kruskal-Wallis H(3) = 51.95, $p < 0.001$, $\varepsilon^2 = 0.54$). Post hoc pairwise comparisons with Bonferroni correction showed that residents scored significantly higher than novices ($Z = -6.04$, $p < 0.001$), intermediates ($Z = -4.31$, $p < 0.001$) and experts ($Z = -4.11$, $p < 0.001$). Median scores and interquartile ranges for each group (maximum score = 31) are shown in Figure 3. Although experts scored slightly higher than intermediates ($Z = -0.26$, adjusted $p = 1.000$) and intermediates scored higher than novices ($Z = -1.14$, adjusted $p = 1.000$), these differences were not statistically significant. The same was true for the comparison between novices and experts ($Z = -1.42$, adjusted $p = 0.93$). However, a Spearman's rank-order correlation revealed a statistically significant positive association between the level of bronchoscopy experience and theoretical exam scores ($\rho = 0.49$, $p = 0.001$).

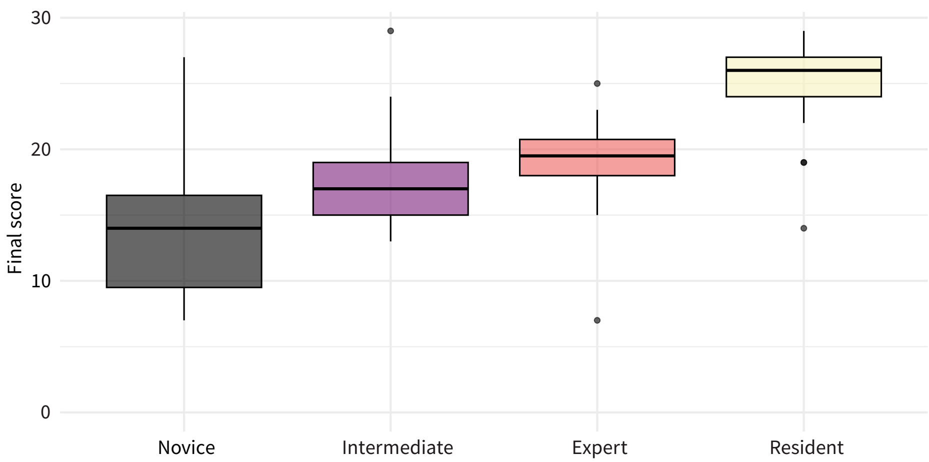

Figure 3: Comparison of final scores for the theoretical exam between novices, intermediates, experts and residents (max = 31).

Implications evidence

Thirty-seven residents (69.8%) passed the anatomy exam at their first attempt, 13 (24.5%) passed the exam at their second attempt and three (5.7%) passed the exam at their third attempt. Regarding the questionnaire, ten instructors (83.3%) responded. Nine instructors rated the residents' preparedness for the simulation-based training in terms of anatomical knowledge as 4 out of 5 and one instructor rated their preparedness as 5 out of 5. As one instructor spontaneously added: "I found most candidates to be very well-prepared and highly motivated to follow the training program". Most instructors (n = 5) required on average per training session an additional 15 minutes to explain anatomy, while two needed no additional time, one required 30 minutes, and two required 1 hour. Table 2 shows failure rates for the theoretical exam across the different groups. Residents had a lower failure rate on the theoretical exam (1.8%, 95% CI: 0.3-9.9%) compared to the unprepared participants (64.3%, 95% CI: 49.2-77.0%). When broken down by subgroup, failure rates were highest among novices (86.7%, 95% CI: 62.1-96.3%), followed by intermediates (69.2%, 95% CI: 42.4-87.3%) and experts (35.7%, 95% CI: 16.3-61.2%).

Table 2: Theoretical exam failure rates per group

Group	Failed (*n*, %)
Novice	13 (86.7%)
Intermediate	9 (69.2%)
Expert	5 (35.7%)
Resident	1(1.9%)

Discussion

This study explored the validity of an anatomy and a theoretical bronchoscopy exam. Kane's validity framework was used as a guiding structure for evaluating the validity of the exams, and multiple sources of evidence were gathered to assess their validity. The *scoring* inference for both exams was supported by the expert-driven development of questions and their refinement by a test expert. For the theoretical exam, this inference was further supported by the observed item difficulty and item discrimination indices. Evidence relevant to the *generalization* inference of the theoretical exam was provided by a Cronbach's alpha of 0.55. The e*xtrapolation* inference for both exams was supported by the Delphi process, in which a panel of international experts assessed question relevance. Additionally, evidence for this inference for the theoretical exam was provided by comparing test performance across different participant groups.

Finally, regarding the *implications* inference, the results suggested that both exams effectively contributed to residents' preparedness for simulation-based training. This was evidenced by the high pass rates, with the vast majority of residents passing the anatomy exam on their first attempt and almost all passing the theoretical exam on their first attempt, in contrast to the higher failure rates for the theoretical exam observed in the other unprepared groups. Additionally, instructors rated the residents' anatomical knowledge as generally good at the start of the training, with most requiring only a small amount of time during the simulation-based training to explain anatomy.

A large proportion of items in the theoretical exam had low discrimination indices, with 19 questions scoring below 0.2. While previous studies on the development of theoretical tests in the field of surgical endoscopy and endosonography [17-18] consistently excluded such questions, we do not regard low item discrimination indices as problematic in our study. Given that nearly all residents passed, it is expected that the questions would not differentiate well between high- and low-performing individuals. This exam was designed to ensure that residents would have adequate (especially anatomy) knowledge before beginning simulation-based bronchoscopy training, rather than to differentiate between varying performance levels on a theoretical exam. This is also reflected in the higher item difficulties in our study (i.e., questions were relatively easy, with the majority of questions having item difficulties between 0.85 and 1.0), whereas in the other studies [17,18], most questions fell within the middle difficulty range (i.e., item difficulty between 0.45 and 0.75). The observed difficulty levels reflect both the nature of the examinee population (a highly selected and motivated group of residents specializing further) and the exam's intent to assess essential knowledge rather than differentiate performance levels. Given these factors, the combination of expert-driven question development, item difficulty, and discrimination values provides strong support for the validity of the scoring inference.

One important aspect of exam quality is whether the items collectively measure the intended construct, which in this study was assessed using Cronbach's alpha. The Cronbach's alpha value for the theoretical exam was 0.55, somewhat below the commonly accepted threshold of 0.7 [19] and lower than the values reported in the other two above-mentioned studies (i.e., 0.75 and 0.91). While a Cronbach's alpha of 0.55 is typically considered 'poor', this was expected given the small number of questions in the exam [20,21], making it an acceptable value of internal consistency for such a short exam. Increasing the number of questions might improve internal consistency and strengthen the *generalization* inference. However, expanding the question set was not feasible due to the limited scope of the subject matter and the risk of excessive repetition. Notably, when combining data from all participant groups, Cronbach's alpha increased to 0.86, indicating strong internal consistency when applied to a more heterogeneous population. When examining groups separately, Cronbach's alpha was 0.80 for the novices, 0.72 for the intermediates and 0.68 for the experts. These findings align with expectations, as participants in these groups had not studied the specific exam material, resulting in greater score variance and consequently, higher internal consistency. Additionally, McDonald's omega total (0.76) and the Spearman-Brown corrected split-half reliability (0.61) suggest a moderate internal consistency, supporting the interpretation that the exam items measured the intended construct.

Although the scores for the theoretical exam slightly improved from novices to intermediates and experts, no significant differences in test performance were observed between these groups. This lack of significance is most likely due to the small group sizes, rather than the absence of differences. Additionally, somewhat surprisingly, 36% of experts failed the exam. However, this outcome is unlikely due to test content irrelevance, as the exam was developed by experts and questions underwent relevance assessment by the international panel. Instead, this finding might be due to different practices across centers, where experts might be adhering to local protocols rather than the BTS guideline. This discrepancy highlights the limitation of relying on experts making a test as a source of validity evidence in these circumstances. Nevertheless, the observed performance differences between the participant groups, despite the small sample sizes, provide some support for the *extrapolation* inference, as the findings suggest that test scores reflect underlying differences in bronchoscopy-related knowledge.

The *implications* inference is considered the most critical [6], as it evaluates whether the exams achieved their intended purpose of ensuring that residents where adequately prepared for simulation-based training. The high pass rates for the theoretical and anatomy exam suggest that the requirement to pass the exams motivated residents to prepare. Additionally, instructor feedback indicated that residents generally had sufficient anatomical knowledge at the start of the training, and little training time was spent on anatomy instruction. However, since there was no control group of residents who did not make the exam but still participated in the training program, it remains uncertain to what extent the anatomy exam itself contributed to the residents' preparedness. Therefore, while these findings provide some support for the *implications* inference, the strength of the evidence remains somewhat limited.

Strengths and limitations

We believe this study has several strengths. First, the exams were thoroughly developed by Dutch pulmonology experts and refined through input from five international experts and one test expert. This ensured a high level of consensus regarding question relevance and clarity. Item discrimination and item difficulty values further supported the strength of the *scoring* inference. Second, the theoretical exam successfully differentiated between participants who prepared for the exam and those who did not, demonstrating its sensitivity to the knowledge acquisition through preparation materials. Third, while no significant differences were observed between novices, intermediates, and experts, a separate Spearman's correlation analysis demonstrated a significant positive relationship between level of expertise and theoretical exam scores (Spearman's $\rho = 0.49$, $p = 0.001$), providing some support for the *generalization* inference. Finally, the high pass rate among pulmonology residents demonstrates that the exam achieved its primary purpose: ensuring participants met the minimum knowledge requirements necessary for participation in the practical simulation-based training.

Despite these strengths, this study also has limitations. First, the theoretical exam included a limited number of questions, which may have limited its internal consistency, consequently limiting the strength of the *generalization* inference. Second, the evidence for the *implications* inference for the anatomy exam in this study was also somewhat weak due to the lack of a control group. Future studies could benefit from incorporating designs that allow for stronger inferences regarding the impact of examination of anatomical knowledge on residents' preparedness during simulation-based training. Third, while ideal testing conditions would have included proctoring, logistical constraints precluded remote supervision of the online exams. Consequently, this absence of controlled testing conditions might have led to an overestimation of anatomical and theoretical knowledge if participants actually used external resources, such as the internet, during the exam. Finally, the strict adherence to the BTS guideline in designing the exam may have reduced its alignment with Dutch clinical practice, potentially impacting the performance of experts who may be familiar with other treatment protocols used in their own hospitals. To improve alignment with actual clinical practice, locally used guidelines should be taken into account when developing future versions of the exam, rather than relying solely on international standards.

Conclusions

This study evaluated the effectiveness of an anatomy and a theoretical exam in ensuring pulmonology residents' readiness for simulation-based training and evaluated their validity using Kane's framework. The validity of the exams was supported by expert involvement in both their design and refinement, combined with acceptable item difficulty, item discrimination indices and internal consistency. The findings suggest that the exams effectively motivated residents to prepare thoroughly, contributing to their acquisition of adequate anatomical knowledge prior to entering the simulation-based bronchoscopy training. These results highlight the value of using exams as entry requirements for simulation-based training, as they enhance residents' preparation, potentially allowing for more time to focus on mastering procedural skills.

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Supplemental material 1: Basic bronchoscopy assessment tool (BBAT)

The correct answer is highlighted in yellow.

Example question anatomy exam

Segment LB4 is also known as

a) Lateral lingular segment
b) Medical lingular segment
c) Inferior lingular segment
d) Superior lingular segment

Example question theoretical exam

Antibioitic prophylaxis before bronchoscopy is warranted in a patient

a) With fever
b) With pneumonia
c) With risk on endocarditis
d) None of the above

Chapter 5

Basic Bronchoscopy Competence Achieved by a Nationwide One-day Simulation-based Training

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Abstract

Background: In 2020, a mandatory, nationwide 1-day bronchoscopy simulation-based training (SBT) course was implemented for novice pulmonology residents in the Netherlands. This pretest–posttest study was the first to evaluate the effectiveness of such a nationwide course in improving residents' simulated basic bronchoscopy skills.

Methods: After passing a theoretical test, residents followed a 1-day SBT course, available in 7 centers, where they practiced their bronchoscopy skills step-by-step on a virtual reality simulator under pulmonologist supervision. Residents practiced scope handling efficiency (task 1) and navigational skills combined with lung anatomy knowledge (task 2). Task 1 outcome measures were navigational skill simulator metrics: percentage of time at mid-lumen, percentage of time with scope-wall contact, procedure time (PT), number of wall contacts and number of wall contacts per minute of PT. Task 2 outcome measures were PT, observational assessment scores of a validated tool with a 5-point scale (1 representing the worst and 5 the best competence) and blinded dexterity assessments.

Results: The study included 100 residents. All outcome measures of task 1 improved significantly ($P<0.001$), except for the number of wall contacts per minute of PT (4.3 [IQR 3.0 to 6.2] pre vs. 3.5 [IQR 2.6 to 5.3] post, $P=0.07$). For task 2, PT was reduced by 54% (10.3±2.7 minutes pre vs. 4.7±0.9 minutes post, $P<0.001$) with an improvement in overall-competence scores (2.0 [IQR 1.0 to 2.0] pre vs. 4.0 [IQR 4.0 to 5.0] post, $P<0.001$) and all dexterity parameters ($P<0.001$).

Conclusion: Nationwide implementation of a SBT course led to rapid improvement of residents' basic bronchoscopy skills while halving PT.

Introduction

Flexible bronchoscopy is a crucial diagnostic and therapeutic tool for various pulmonary diseases, such as lung cancer [1]. The procedure is safe, although it is important to note that complications, while rare, can be life-threatening [2]. To minimize patient burden and ensure their safety, pulmonologists should be adequately trained. Traditionally, bronchoscopy training took, and in some training centers still takes place, through the "apprenticeship method," where a novice resident would start performing a bronchoscopy on patients under supervision of an experienced pulmonologist without any simulation-based training (SBT). This training method is associated with increased patient discomfort, longer procedure time (PT) and higher complication rates compared with patients undergoing bronchoscopy by a more experienced bronchoscopist [3–5]. Over the past 2 decades, there has been an increase in the use of simulation to teach bronchoscopy skills and competence to trainees. This increased uptake has also led to several studies evaluating bronchoscopy SBT courses, with the majority demonstrating effectiveness of SBT to teach bronchoscopy skills to novice trainees, according to a previous review [6]. Despite favorable outcomes, most studies in this review were low-powered, were conducted in a single-center setting and/or included participants that were nonrepresentative for the pulmonologist population (e.g., medical students), which could have led to biased results [7]. Furthermore, as far as we know the effectiveness of the implementation of a bronchoscopy SBT course on a nationwide scale has not been studied yet. In light of the perceived benefits of SBT, the Dutch Association of Chest Physicians (NVALT) implemented a mandatory nationwide 1-day flexible bronchoscopy SBT course for first-year pulmonology residents in 2020. This initiative presented an opportunity to investigate the effectiveness of a nationwide bronchoscopy SBT course for residents on basic bronchoscopy skills. With this study, we aimed to enhance our understanding of the effectiveness of a flexible bronchoscopy SBT program that was implemented on a nationwide scale.

Methods

Course development and implementation

The SBT course was developed collaboratively by pulmonologists/simulation experts from 6 simulation centers, the research team, and 2 international renowned colleagues with expertise in medical SBT. A series of online and on-site meetings were conducted to establish consensus on course content and assessment methods. Based on this input and a cognitive task analysis [8], it was decided to focus the training on teaching residents basic bronchoscopy competence, implicating that at the end of the course residents should be able to navigate through the bronchial tree with proper scope handling (dexterity) and should be able to adequately enter and identify all airway segments, the cornerstones of bronchoscopy [9]. The assessment procedure was designed to evaluate trainee competence aligned with these training objectives. In addition, all researchers and trainers agreed that a maximum of two residents could attend each training day, aiming for an optimal interaction and a safe learning environment. The training sessions were led by either 1 pulmonologist, 1 pulmonologist who could be assisted by a simulation expert, or 2 pulmonologists, depending on the training center. Several pilots were conducted to determine the feasibility of the course program and to calibrate the assessors' evaluation of the simulated bronchoscopies, and subsequently, an additional center joined the simulation initiative network.

Participants

All first-year Dutch pulmonology residents were obliged to follow the 1-day training course, although residents who had performed more than 50 clinical bronchoscopies before the start of the training were excluded from the study. Data collection took place from May 2021 until May 2023. Ethical approval for this study was obtained from the ethical review committee of the University of Twente. Before the training, residents received verbal information and an information letter, followed by the opportunity to provide informed consent for participation. The training course was standardized for all trainees, irrespective of their participation in the study. The only distinction was that data of consenting trainees would be collected and analyzed anonymously. Both the verbal information and the information explicitly stated that participating in the study would not affect a trainee's chances of passing the training. This study was carried out in accordance with the Declaration of Helsinki [10].

The simulator utilized for the training course by every center was the virtual reality GI-BRONCH Mentor flexible bronchoscopy simulator (MentorLearn software version 2.5.5.63, Surgical Science, Göteborg, Sweden). Within this training program, the Essential Bronchoscopy and Diagnostic Bronchoscopy modules were employed. The Essential Bronchoscopy module comprised several tasks, with residents practicing solely the Basic scope manipulation task and Lung anatomy and bronchial segments task, referred to as, respectively, task 1 and task 2 to enhance clarity. The Diagnostic Bronchoscopy module included various patient cases, allowing residents to select randomly the cases they wished to practice.

The training course

Before participating in the course, residents were required to read study material related to bronchoscopy [11–14] and pass a theoretical exam evaluating their knowledge of bronchial anatomy, indications, contraindications, and complications. This examination was developed by a team of experienced pulmonologists, and all questions underwent relevance assessment by 5 international experts through a Delphi procedure. The main goal of this exam was to ensure residents had adequate bronchial anatomy knowledge, so that insufficient knowledge would not hinder them in completing the training.

Figure 1 shows the course structure. The individual pretest and posttest assessment consisted of task 1 and task 2, aimed at assessing residents' simulated basic bronchoscopy competence. Task 1 involved following a ball through a digital maze. Residents were allowed to do a practice run first (however, only in the pretest session), followed by 5 actual runs, randomly selected from 8 trajectories. Performance metrics recorded after each run included PT, % of time at mid-lumen, % of time with scope-wall contact and the total number of wall contacts. Task 2 required residents to navigate to and name all airway segments, 10 in the right lung and 8 in the left lung, systematically from 1 to 10. Adequate navigation to a segment was confirmed by the appearance of a green circle around question mark within the segment on the screen. Subsequently, residents had to state the anatomical name and corresponding segmental number, after which the trainer selected the name on the screen. For this anatomy task, assessment was conducted using a previously validated bronchoscopy assessment tool [15] adapted to the simulation procedure. We decided not to use the Bronchoscopy Skills and Task Assessment Tool (BSTAT) [16] because it includes parameters for assessing the ability to describe mucosal abnormalities and perform interventions such as bronchoalveolar lavage or brushing, which were beyond the scope of our training program. Our basic bronchoscopy assessment tool (BBAT) comprised 10 parameters, yielding an overall-competence score on a scale of 1 to 5, where 1 represented the worst and 5 the best competence (Supplemental material 1). A final score of 3 or higher was required for trainees to pass the training course. Since this tool relied on direct observation and some parameters can thus be subject to bias, video recordings of residents' performances during this task were made for subsequent dexterity assessment by a blinded expert rater and comparison to the unblinded BBAT ratings at a later stage (see below for a detailed description for this dexterity assessment). During all practice sessions following the pretest, the trainees were continuously supervised by the trainer(s), receiving procedural information in the form of how-to instructions and corrective feedback.

Outcome measures

For task 1, outcome measures were average values of each of the four simulator metrics (PT, % of time at mid-lumen, % of time with scope-wall contact and the number of wall contacts). In addition, considering that longer procedure durations may result in increased wall contacts, the number of wall contacts per minute of PT was calculated and included as an extra outcome measure for this task. Regarding task 2, outcome measures were (1) PT, (2) overall-competence scores of the BBAT (Supplemental material 1), and (3) blinded expert ratings of residents' dexterity in the video recordings, for which a separate assessment tool was developed. A detailed description of the various parameters of this assessment tool is provided below.

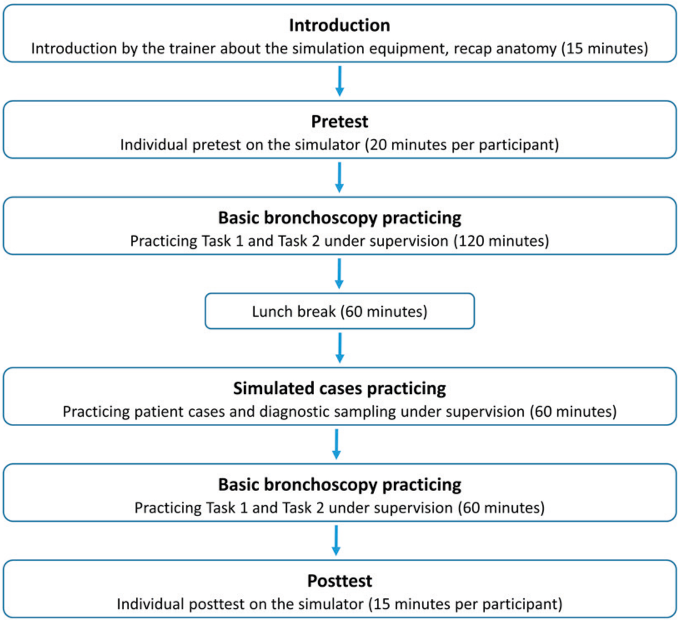

Figure 1: Overview of the training program.

Bronchoscopy Dexterity Assessment Tool: blinded assessment

To collect additional validity evidence for the BBAT, a bronchoscopy dexterity assessment tool (BDAT) suitable for blinded evaluation was developed (see Supplemental material 2). The video recordings exclusively captured the bronchoscope and the participant's arms and hands (a screenshot of a video recording is shown in Supplemental material 3). The BDAT encompassed 4 parameters, "movements in horizontal plane" (1), "scope bending" (2), "deliberate wrist movements" (3), and "hand thumb position" (4) resulting in a composite "total score". The tool also included an overall assessment parameter: "fluency" (5). The inclusion of these parameters was based on the literature [14,17,18] and expert opinion. Essentially, correct navigation of the bronchoscope involves movements only being limited to a vertical plane coupled with rotation, flexion and deflexion of the tip. Movements in the horizontal plane (1) and scope bending (2) are deemed redundant, as they do not facilitate proper movement of the tip of the bronchoscope. The operator should only make deliberate wrist movements (leading to rotation of the scope) necessary for adequate scope navigation (3) with the thumb continuously placed on the steering lever to initiate tip flexion or deflexion (4). In addition, the entire procedure should ideally be performed fluently (5). Fluency in this regard might be seen as an overall global judgment of the operator's dexterity.

Statistics

The data were analyzed using SPSS, version 26. Paired t tests were employed to compare the normally distributed values: % of time at mid-lumen and % of time with scope-wall contact for the first task, and PT for the second task. For the non-normally distributed values, the Wilcoxon-signed rank test was utilized. In addition, a Bonferroni corrected significance threshold was calculated [19], resulting in a corrected threshold of $\alpha=0.025$ for the % of time at mid-lumen and % of time with scope-wall contact in the first task and $\alpha=0.0167$ for the number of wall contacts, PT and the number of wall contacts per minute of PT in the first task. For PT and BBAT overall-competence scores of the second task, the corrected significance threshold was $\alpha=0.025$. Finally, for the BDAT ratings, the resulting threshold was $\alpha=0.01$. Effect sizes were calculated using Cohen's d, with values of 0.2, 0.5, and 0.8 indicating small, moderate, and large effect sizes, respectively. Spearman ρ was used to measure correlation between the movement in horizontal plane parameters of the unblinded BBAT and blinded BDAT, given their non-normal distribution. Spearman ρ values of 0, 0.1 to 0.3, 0.4 to 0.6, 0.7 to 0.9, and 1, respectively, indicate zero, weak, moderate, strong, and perfect correlation [20].

Results

The data collection process continued until 100 participants were included. Median age of participants was 31 years, with the 25th and 75th percentiles ranging from 29 to 33 years. Their demographics are described in Table 1. The majority (n=77, 77%) had performed 10 or fewer bronchoscopies before participating in the training. Most participants had not previously practiced on a simulator (n=70, 70%). The number of participants in the different centers was balanced, except for Enschede, where only 4 residents participated in the study.

Pretest and posttest results for all outcome measures of task 1 are described in Table 2. A significant difference between the posttest and pretest was observed for all outcome measures, except for the number of wall contacts per minute of PT. The effect sizes, ranging from −0.4 to −0.7 for the significantly differing outcome measures, indicate moderate to large effects of the training course on basic scope navigation skills.

Figure 2A and B shows pretest and posttest outcomes for task 2. Only 3 residents failed (i.e., they had an overall-competence score lower than 3). A significant improvement was observed for both time (10.3±2.7 min pre vs. 4.7±0.9 post, $P<0.001$, 95% CI of the difference=−5.1 to −6.0, paired samples t-test) and BBAT overall-competence scores (2.0 [IQR 1.0 to 2.0] pre vs. 4.0 [IQR 4.0 to 5.0] post, 95% CI of the difference=2.0-2.0, $P<0.001$, Wilcoxon-signed rank test). Effect sizes were, respectively, −2.3 and 0.9, indicating a large effect of the training course on both time and basic bronchoscopy skills.

Table 1: Participant demographics.

Demographic category	Demographic	Participants, N
Gender	Male	33
	Female	67
Bronchoscopy experience	None	33
	1-10	44
	11-50	23
Gaming experience	None	82
	<1 hour per month	2
	1-10 hours per month	9
	≥10 hours per month	7
Simulation experience	None	70
	<30 minutes	17
	≥30	13
Training center	Amsterdam	20
	Eindhoven	16
	Enschede	4
	Groningen	11
	Leiden	18
	Maastricht	17
	Nijmegen	14

Table 2: Task 1 simulator metrics.

Outcome measure	**Pretest mean ± SD / Pretest median [25th-75th percentile]**	**Posttest mean ± SD / Posttest median [25th-75th percentile]**	**P-value (95% CI of difference)**	**Cohen's *d***
total time (seconds)	38.1[29.8-46.7]	31.1[24.1-39.2]	<0.001* (-10.6 – -5.1)	-0.6
percentage of time at mid-lumen	58.5 ± 8.6	62.2 ± 7.8	<0.001* (2.0 – 5.3)	0.4
percentage of time with scope-wall contact	10.7 ± 5.3	8.3 ± 4.6	<0.001* (-3.5 – -1.4)	-0.5
number of wall contacts	2.6[2.0-3.8]	2.0[1.4-2.6]	<0.001* (-1.2 – -0.7)	-0.7
number of wall contacts per minute procedure time	4.3[3.0-6.2]	3.5[2.6-5.3]	0.07 (-0.9 – -0.07)	-0.2

Paired samples t-test for normally distributed outcome measures, Wilcoxon signed-rank test for non-normally distributed outcome measures. CI = Confidence Interval.
* = statistically significant difference.

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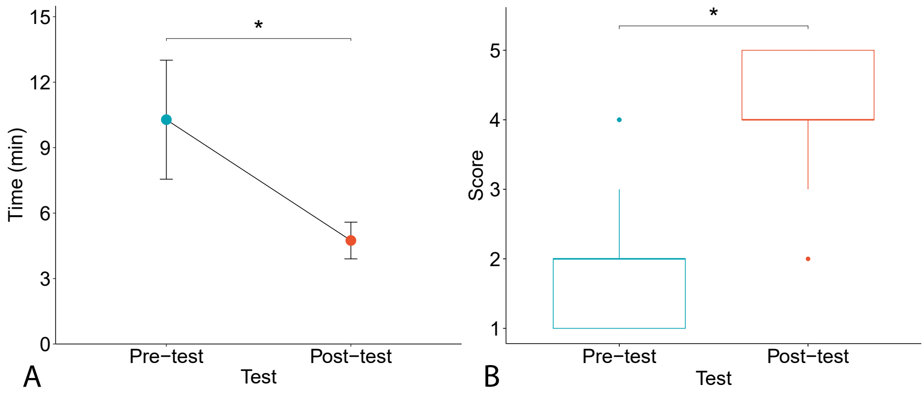

Figure 2: Pretest and posttest task 2 procedure time (A) and overall-competence scores on the basic bronchoscopy assessment tool (BBAT) on a scale of 1 to 5 (B). Paired samples t-test for procedure time and Wilcoxon-signed rank test for overall-competence scores. *P<0.001.

Table 3: Task 2 dexterity parameters median [25th percentile-75th percentile], rated by a blinded expert (n=62 residents).

Outcome measure	Pretest median [25th – 75th percentile]	Posttest median [25th – 75th percentile]	*P* (95% CI of the difference)	Cohen's *d*
Hand thumb position (max 5)	2[1-3]	2[2-4]	<0.001* (0.0 – 0.5)	0.5
Movements in horizontal plane (max 5)	2[1-3]	4[3-4]	<0.001* (1.0 – 1.5)	0.8
Bending (max 5)	2[2-3]	4[3.75-5]	<0.001* (1.5 – 2.0)	0.6
Deliberate wrist movements (max 5)	2[2-3]	4[3-4]	<0.001* (1.0 – 1.5)	0.8
Total score (max 20)	9[8-12]	15[12-16]	<0.001* (4.0 – 5.0)	0.8
Level of fluency (max 5)	2[1-3]	4[3-4]	<0.001* (1.5 – 2.0)	0.8

Parameters were rated on a scale of 1-5, where a higher score indicated better dexterity on each parameter. CI = Confidence Interval. * = statistically significant difference.

Blinded expert ratings of dexterity

Pretest and posttest results for all parameters of Task 2 that were rated by the blinded expert with the BDAT are shown in Table 3. All outcome measures improved significantly. The effect sizes, ranging from 0.5 to 0.8, indicate moderate to large effects of the training course on parameters associated with dexterity. Following the evaluation of the first 62 residents, an interim analysis was conducted. This revealed a moderate Spearman rank correlation coefficient between the unblinded on-site BBAT and the blinded BDAT ratings of movements in the horizontal plane for both the pretest and posttest dexterity ratings, respectively ρ=0.6, P<0.001 and ρ=0.4, P=0.002. Based on these interim results, it was decided to discontinue the blinded ratings as further adding more blinded, very time-consuming evaluations, most probably would not change the final results or conclusions.

Discussion

This article presented the first evidence of the effectiveness of a 1-day SBT course in improving basic bronchoscopy competence when implemented on a nationwide scale. With this course, residents significantly improved their basic bronchoscopic competence to a large extent. In a basic navigation task, nearly all simulator metrics improved significantly. More importantly, in a realistic anatomical task, PT was reduced by half, accompanied by a significant enhancement in basic bronchoscopic competence from a median level of 2 (novice) to a median level of 4 (competent). This enhancement was evidenced by the improvement of all participants' BBAT overall-competence scores and blinded expert ratings of the first 62 participants' dexterity. Notably, the vast majority of effect sizes for the outcome measures of this task were ≥0.8, suggesting a strong impact of the SBT course on residents' skills in an anatomically realistic simulated environment.

This study used various methods to assess residents' bronchoscopy competence, enhancing result robustness. Simulator-generated metrics were used for task 1, offering objective measurements that have been shown to correlate with bronchoscopist skill levels [21]. However, this task involves following a ball through a digital maze while keeping the scope centralized, which may reflect dexterity in general, but may, on the other hand, not be directly relevant to clinical bronchoscopy skills. Previous research also showed that novices could quickly learn how to achieve high scores on task 1 [17]. Furthermore, our study demonstrated a lack of improvement in the number of wall contacts per minute of PT in task 1, potentially indicating its limited validity. Despite these limitations, incorporating task 1 in training programs can still be valuable, as it serves as an additional exercise to familiarize residents with basic scope navigation in the initial phase of their training and introduces some variety in the program. Nevertheless, for basic bronchoscopy assessment purposes, we believe task 1 has limited value, as it does not evaluate anatomy knowledge competence, navigational skills in an anatomical environment and dexterity, which were our key training objectives. These major objectives, necessary for achieving basic bronchoscopic skills, were assessed in task 2 with a validated bronchoscopy assessment tool adapted to a simulation setting. This BBAT however relies on direct observation, which introduces the possibility of bias for some parameters. Although the anatomical parameters are measured rather objectively (i.e., raters can easily tell if a resident named a segment correctly or was able to enter it), the qualitative ratings of the tool's dexterity parameters might be susceptible to some degree of subjectivity. Therefore, video recordings were used to circumvent this subjectivity for the dexterity parameters to enable blinded assessment with the BDAT [22,23]. Moreover, the moderate correlation between the unblinded and blinded ratings of the "movements in horizontal plane" dexterity parameters indirectly supports the validity of the unblinded ratings.

A recent systematic review on the effectiveness of bronchoscopy SBT concluded that SBT probably is an effective training method for teaching basic bronchoscopy skills to novice trainees [6]. However, the vast majority of the included studies were single-center and included less than 30 participants. The success of these small-scale, highly controlled simulation interventions observed in previous research may not necessarily translate to success when implemented on a larger scale, also because transferring successful programs to real-life settings is complex [24,25]. Previous research has also shown that an implementation gap in other SBT fields still exists [26]. Despite these concerns, our study shows that even a nationwide implementation of this bronchoscopy SBT program is feasible and effective in achieving basic bronchoscopy competence in novice residents.

Strengths and limitations

Major strengths of this study include the careful design of the training program, involving medical education, simulation, and pulmonology experts. Second, data were obtained in a nationwide training setting, encompassing 7 different training centers. Third, the number of participants was high, more than in any previous bronchoscopy simulation study, contributing to the robustness of the results. Finally, the validity of our findings regarding dexterity was confirmed by blinded ratings, which was omitted in most previous studies.

This study has also several limitations. First, we employed a pretest–posttest design, which, although commonly used, may be considered less robust than other designs because a pretest can influence the results of the posttest. However, ethical considerations and the mandatory nature of our training course precluded alternative designs. On the other hand, recent preliminary data showed no effect of the pretest on posttest results. Second, our study did not measure long-term retention following the training course, although a study is currently underway to assess this. Third, although the study focused on novice residents, a small number of participants had some bronchoscopy experience, potentially introducing some heterogeneity in the measured baseline skill levels. Fourth, although the dexterity assessment with the BDAT highlighted improvements in scope handling and provided validity evidence for the BBAT, it is important to note that this tool requires further validation before it can be used in other studies. Fifth, another limitation of our study is that we did not employ the widely used BSTAT for reasons discussed in the methods section, making it challenging to compare our results with those of other studies. Finally, we did not measure outcomes in a patient setting, highlighting a need for future bronchoscopy simulation studies to evaluate trainees' skills in a patient setting following SBT.

Conclusions

This study demonstrated that a 1-day nationwide bronchoscopy simulation-based training course significantly improved pulmonology residents' basic bronchoscopic competence in an anatomically realistic simulated task to a large extent, whereas procedure time was halved. Therefore, bronchoscopy simulation-based training has now, for the first time, been proven to be a highly effective training method when implemented on a nationwide scale.

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Supplemental material 1: Basic bronchoscopy assessment tool (BBAT)

Bronchomotor skills

1. Scope introduction
    3. In 1 try
    2. In 2 tries
    1. In 3 or more tries

2. Right lung
    3. All segments entered correctly
    2. 1 segment not entered correctly: segment ___
    1. 2 or more segments not entered correctly: segments ___

3. Left lung
    3. All segments entered correctly
    2. 1 segment not entered correctly: segment ___
    1. 2 or more segments not entered correctly: segments ___

4. Procedure
    3. All segments L+R systematically reached
    2. Only segments in L or R systematically reached
    1. Segments in both L and R not systematically reached

5. Intra-bronchial scope movement overall
    5. No unnecessary wall contacts, good centralization of the scope
    4.
    3. Moderate amount of wall contacts, moderate centralization of the scope
    2.
    1. Many wall contacts, bad centralization of the scope

6. Dexterity
    5. No unnecessary movements in the horizontal plane
    4.
    3. Moderate amount of unnecessary movements in the horizontal plane
    2.
    1. Many unnecessary movements in the horizontal plane

7. Hand-wrist movements
    5. Right position of hand and fingers during the procedure with a relaxed posture
    4.
    3. Right position of hand and fingers during the procedure with too much tension
    2.
    1. Wrong position of hand and fingers during the procedure with too much tension

8. Procedure time:_______

Anatomy

9. Right lung
    3. All segments correctly named (name and number)
    2. 1 segment incorrectly named: segment ___
    1. 2 or more segments incorrectly named: segments ___

10. Left lung
    3. All segments correctly named (name and number)
    2. 1 segment incorrectly named: segment ___
    1. 2 or more segments incorrectly named: segments ___

Overall rating

5. Very good
4. Good
3. Average
2. Bad
1. Very bad

Supplemental material 2: Bronchoscopy dexterity assessment tool (BDAT)

Item	Subscore	Score	Explanation
Hand thumb position	NA		Level 1-5: 1 < 20%, 2 < 40%, 3 < 60%, 4 < 80%, 5> 80 % of time correct
Movements in horizontal plane: level of discrepancy			1 = high and 3 = low level of discrepancy
Movements in horizontal plane: time			1 < 1/3 time, 3 >2/3 time correct
Movements in horizontal plane: final score	NA		Score = level + time: 2 = 1, 3 = 2, 4 = 3, 5 = 4, 6 = 5
Bending: level of discrepancy			1 = high degree of bending i.e. > 60 degree and 3 = low, i.e. <20 degree
Bending: time of suboptimal bending			1 < 1/3 time, 3 >2/3 time correct
Bending: final score	NA		Score = level + time: 2 = 1, 3 = 2, 4 = 3, 5 = 4, 6 = 5
Deliberate wrist movements: level			1: being extremely dysfunctional, 3: only minimal
Deliberate wrist movements: time			1 < 1/3 time, 3 >2/3 time correct
Deliberate wrist movements: final score	NA		Score = level + time: 2 = 1, 3 = 2, 4 = 3, 5 = 4, 6 = 5
Total score	NA		Maximum 20
Level of fluency	NA		Maximum 5, 1 = extremely disfluent, 5 = extremely fluent

Supplemental material 3: Screenshot of a video recording used by the blinded rater for the dexterity assessment

Chapter 6

Development, implementation and evaluation of a bronchoscopy simulation training program for intensive care Fellows and intensivists in the Netherlands

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Abstract

Simulation-based training can be valuable for teaching bronchoscopy to intensivists, providing a risk-free training environment. We developed, implemented and evaluated a simulation-based flexible bronchoscopy training program for intensive care fellows and intensivists. This paper presents the development of its design and lessons learned. We used the ADDIE model for developing and evaluating the training program (Analysis and Design – phase 1, Development – phase 2, Implementation – phase 3, Evaluation – phase 4). In phase 1, 2 intensivists formulated learning objectives for bronchoscopy in an intensive care setting, which guided the identification and development of training materials and the preliminary training program (phase 2). In phase 3, we tested this program and gathered feedback from participants to guide program modifications. After implementing the adjusted training, we measured participants' satisfaction using a survey based on closed- and open-ended questions (phase 4). 57 participants attended the training, with 18 (32%) responding to the questionnaire. Respondents highly appreciated the training program, with median satisfaction scores of 4 or higher on a 5-point scale for all closed-ended questions. Respondents appreciated the supervision and feedback and found the simulator equipment relevant for learning bronchoscopy. The paper's description of the program's development and its evaluation results can serve as a valuable resource for those wishing to establish similar training programs. We recognize that further implementation of evidence-based instructional design principles might enhance the training program's scientific foundation and effectiveness. We therefore recommend a more evidence-based approach for the design of future bronchoscopy simulation training programs.

Introduction

Bronchoscopy procedures are commonly performed in the intensive care unit (ICU) for both diagnostic and therapeutic purposes [1]. In rare cases, however, serious and potentially life-threatening complications can occur [2]. The risk of such complications is higher in critically ill ICU patients [3]. In the Netherlands, as in many European countries, experienced pulmonologists are not routinely part of the ICU team and may not be immediately available when an acute bronchoscopy is needed. To help meet this demand, it is important that intensivists, too, have the skills to perform bronchoscopy in acute settings. This calls for adequate training of ICU specialists. As with many other procedural skills, the initial phase of such bronchoscopy skills training should ideally be simulation-based. Simulation-based training (SBT) has shown to positively affect patient safety, the learner's learning curve, and the additional costs associated with occupying an operating theatre during a learning situation [4,5]. Moreover, learning a procedure on patients when a simulation model is available is ethically questionable [6]. For these reasons, SBT is to be preferred to non-simulation-based training in an apprenticeship model.

Several studies have investigated the use and effects of simulation-based flexible bronchoscopy training [7-9]. To our knowledge, however, all training programs hitherto described were specifically designed for pulmonologists. In the Netherlands, intensivists have different roles in clinical practice and, consequently, they have also received different training with less or no focus on bronchoscopy skills. We therefore sought to develop a simulation training program specifically for intensive care fellows and intensivists but also for other physicians working in ICU, to evaluate participant satisfaction following implementation and share lessons learned with the intensivist community.

Materials and methods

We first defined the learning objectives for a simulation-based bronchoscopy training program in a critical care setting. Based on these objectives, we designed a preliminary training program which we first tested and subsequently adapted based on participant feedback. We then implemented the revised program, and measured participant satisfaction afterwards to evaluate the training program, identifying training components that were most valued in the process.

The Analyse, Design, Develop, Implement and Evaluate (ADDIE) model

We employed the ADDIE model to retrospectively describe the process of developing, implementing and evaluating the bronchoscopy training program. This model is widely used by instructional designers to develop courses and training programs [10,11]. Figure 1 shows a flowchart with a brief description of each of the four ADDIE Phases as described in this article, but in the following, we will describe each phase in more detail.

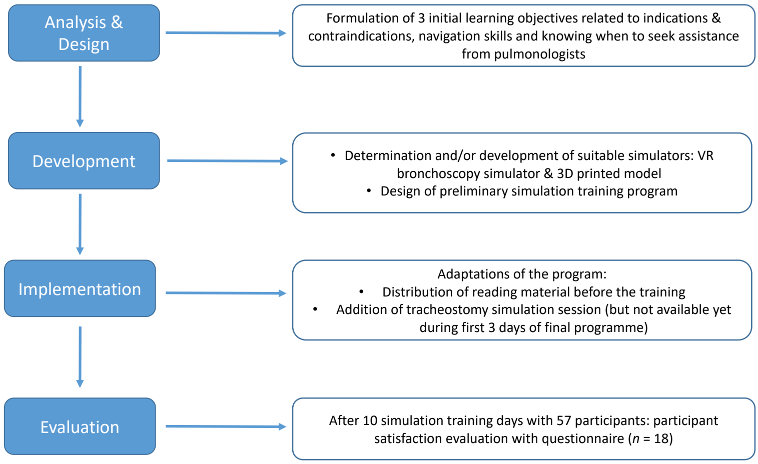

Figure 1: ADDIE model flowchart.

Phase 1: Analysis and design

In 2018, two intensivists (RS and US) from Maastricht University Medical Center+ (MUMC+), one of whom is also a pulmonologist, engaged in discussions about developing a bronchoscopy training program for intensivists. They both recognized the widespread use of bronchoscopy in the ICU and the need for intensivists to acquire bronchoscopy skills as experienced pulmonologists were not always available. If intensivists were trained to perform bronchoscopies in the ICU, this would improve the care of critically ill patients. The primary aim of the intended training program should be to teach intensive care fellows and intensivists basic bronchoscopy skill. However, they also decided to make the course available for other physicians also working in the ICU if space would be available. Consensus was that the program should focus on the cornerstones of bronchoscopy, i.e. knowledge of its indications, its technique and bronchial anatomy [12]. Therefore, the first two learning objectives were: 1) being able to identify appropriate indications and relative contraindications for performing bronchoscopy in the ICU, and 2) being able to navigate the bronchial tree adequately (without unnecessary bronchial wall contacts and with proper hand-eye coordination) while recognizing the different lobes. Pulmonologists were invited to provide feedback on the learning objectives, which was fairly positive. However, they also emphasized that recognizing situations requiring the expertise of a pulmonologist should be a key learning outcome of the training, leading to a final third learning objective.

Phase 2: Development of training materials

A flexible virtual reality (VR) bronchoscopy simulator (Simbionix BRONCH Mentor, SurgicalScience, Sweden) (see Figure 2) was already available in the MUMC+ simulation center. This simulator allowed trainees to practice their bronchoscopy skills at different levels, ranging from basic navigation skills to actual diagnostic and therapeutic patient cases. To enhance the fidelity of the learning experience and to achieve the learning objectives, the training developers collaborated with the Instrument Development, Engineering & Evaluation (IDEE) department at Maastricht University to create an anatomically accurate model for training navigation skills and interventions such as sputum aspiration. Aided by a thoracic radiologist, the IDEE department eventually constructed a 3D-printed model of a bronchial tree based on a thorax CT scan that could also be used for aspiration of fluids (see Figure 3).

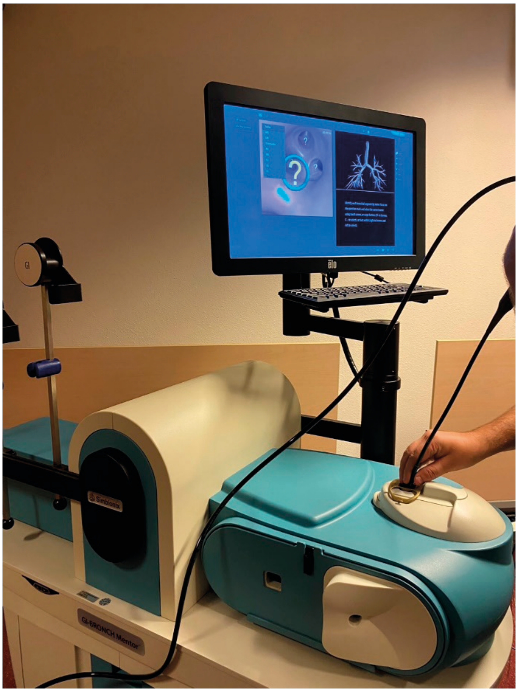

Figure 2: The Simbionix BRONCH Mentor flexible bronchoscopy simulator with the lung anatomy and bronchial segments task from the Essential Bronchoscopy module.

Based on existing literature and the learning objectives and training materials thus obtained, we went on to design a preliminary simulation training program that lasted one day (see Table 1). In the session with the VR simulator, participants started with some basic simulation tasks to familiarize themselves with navigating the scope, and then, if their skill level allowed, moved to more complex diagnostic and therapeutic patient cases. The session with the 3D-printed anatomical model comprised practicing navigation skills and aspiration interventions, using red soap infused in the model to mimic blood. Instruction was provided by the training developers RS and US, both with extensive experience in performing clinical bronchoscopies and in training residents, for which they followed the mandatory train-the-trainer courses at the MUMC+ on how to give meaningful feedback to residents in the workplace. Each session could accommodate three participants at a time, with the groups rotating after finishing their session.

Figure 3: The 3D-printed anatomical model developed by the IDEE department. The box contains two lung models, each consisting of two parts. One part is suitable for inspection bronchoscopy only (depicted as I in the figure), while the part with the intrabronchial line (depicted as A in the figure) can also be used to infuse the model with colored soap to mimic blood or sputum, making it suitable for the simulation of aspiration of secretions in the endobronchial tree. Each part can be attached to and detached from the trachea by means of small magnets (depicted by M in the figure).

Phase 3: Implementation of the simulation training program and its further development

The training developers piloted the preliminary program on colleagues from the ICU department during three separate days. Based on the feedback obtained, we made several final changes to the program. First, we ensured that participants received the reading materials a few weeks ahead of the training to give them the opportunity to prepare and optimize learning outcomes [13-15]. Second, the participants in this pilot recommended adding a simulation session to the program to practice using the bronchoscope during a percutaneous tracheostomy procedure, which is a common intervention in most ICUs. Consequently, the IDEE department was asked to develop a realistic 3D-printed tracheostomy training model that could be inserted into a mannequin (herein, the Advanced HAL S3201, developed by Gaumard, Miami, Florida). This mannequin features a pre-existing trachea opening, equipped with a standard trachea model. However, the standard model could not be used to simulate a complete tracheostomy procedure due to the texture of the material. The new model developed by the IDEE department (see Figure 4) allows trainees to practice a complete and realistic percutaneous tracheostomy procedure under bronchoscopic guidance.

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The tracheostomy simulation procedure involved identifying anatomical landmarks, puncturing the trachea under bronchoscopic guidance, introducing the guidewire, and dilating the trachea with small and larger dilators. Finally, the trachea cannula was introduced, and the bronchoscope was used to confirm its correct placement.

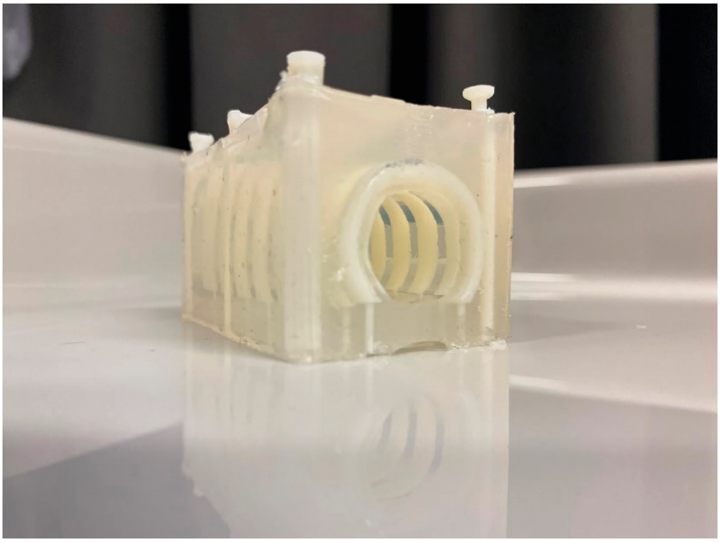

Figure 4: The 3D-printed tracheostomy training model that can be inserted into a training mannequin.

Table 1: Content of the preliminary and final simulation training program.

Activity	Subject/description (duration)	Preliminary	Final
Reading materials	- The Dutch Thoracic Society outline for bronchoscopy in ICUs - links to bronchoscopy websites (n/a)	Available during the training	Distributed beforehand
Presentation	Indications, contraindications and preparations for bronchoscopy (by pulmonologists) (45 min.)	+	+
Presentation	Bronchial/segmental anatomy (30 min.)	+	+
Presentation	Clinical cases (45 min.)	+	+
Presentation	The bronchoscope (30 min.)	+	+
Simulation session 1	Simbionix simulator exercises (30 *or* 60 min.)	+ 60 min.	+ Session 1 and 2 combined: 120 min. on day 1 – 3 60 min. on day 4 – 10
Simulation session 2	Practical exercises (aspiration interventions) with the 3D-printed bronchial anatomical model (30 *or* 60 min.)	+ 60 min.	
Simulation session 3	Tracheostomy simulation procedure (60 min.)	-	+ Only available on day 4 – 10.
Verbal evaluation	Participants are invited to provide verbal feedback and evaluate the training program (15 min.)	+	+

N/A = not applicable as no allocated duration was made for this activity; + = included in the training program; - = not included in the training program.

After these training program adaptations, we implemented the final program (see Table 1) in 10 separate runs at the MUMC+ simulation center in the period spanning 6 June 2019 to 8 April 2022. The training program was non-mandatory, and participants could voluntarily participate based on their interest and how well it aligned with their clinical responsibilities. The program was open to healthcare professionals from various hospitals across the southern region of the Netherlands. To ensure optimal interaction and a safe learning environment, each training day accommodated a maximum of six participants. The tracheostomy training model was not available until February 2020 and was therefore only used in the last seven training days. Once the model was available, the sessions with the VR simulator and the 3D-printed anatomical model were combined. This arrangement allowed three participants to join the tracheostomy simulation session, while the other three alternated between the VR simulator and the 3D anatomy model. This approach ensured no extra instructors were needed and kept group sizes small. No additional program changes were made.

Phase 4: Evaluation: participants' satisfaction

To assess the perceived relevance of the simulation training and participants' satisfaction with its contents, materials and supervision quality, we developed a questionnaire. This questionnaire comprised open-ended questions and closed-ended questions or statements to be rated on a 5-point Likert scale (1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree, 5 = strongly agree). Drawing from several papers addressing student satisfaction with bronchoscopy SBT or simulation-based learning in general [16-20], the first author (EG) created a first draft of the questionnaire, with 7 open-ended questions and 19 closed-ended statements. Four of the other authors consequently reviewed this initial draft (RS, MG, WvM, FS) in two separate rounds. This step led to the addition of four open questions and six statements, the omission of five statements, and minor adaptations to five statements. The final questionnaire [see Supplemental material 1], with 11 open-ended and 20 closed-ended statements, was then sent out to all participants. All open-ended questions were mandatory, ensuring responses from all participants. The qualitative data from the open-ended questions were analyzed on common themes by the first and last author (EG and RS). After an independent scrutiny, the two authors held a consensus meeting to compare the results from their individual analyses and resolve any discrepancies. In case discrepancies could not be resolved, the team as a whole discussed the matter and took a final decision.

Survey results were analyzed using IBM SPSS statistics (version 28; IBM Corp., Armonk, NY, USA). Given the non-normal distribution of the statement results, differences between the participant categories were compared with the Kruskal-Wallis test. Bonferroni correction resulted in a corrected threshold of $\alpha = 0.0025$.

Ethics

This study was carried out in accordance with the Declaration of Helsinki. Completing the survey was voluntary and entirely anonymous. Before filling in the questionnaire, participants gave their informed consent by completing the designated form they had received together with the questionnaire link. Dutch law stipulates that ethics approval is only needed when a study falls under the Medical Research Involving Human Subjects Act. As an anonymous, short questionnaire that does not contain any sensitive questions, our survey did not fall under this act [21,22]. Consequently, it did not qualify for review by an institutional ethics committee.

Results

All training days were quickly fully booked, indicating a high level of interest. The implementation of the adapted training proceeded without any issues. The training days were attended by a total of 57 participants, predominantly intensive care fellows and intensivists (n = 45, see Table 2).

Table 2: Background of training participants.

Participant category	Primarily (being) trained as	Number of participants
Intensivists	Internist	23
	Anesthesiologist	5
	Cardiologist	2
	Surgeon	1
Fellow intensivists	Anesthesiologist	7
	Internist	4
	Cardiologist	2
	Surgeon	1
Residents	Pulmonologist	3
	Anesthesiologist	1
Non-ICU physicians	Physician assistant	5
	Anesthesiologist	1
	Emergency physician	1
	Foundation physician	1

In this context, the term ‘intensive care fellows’ refers to physicians undergoing super- or intra-specialty training in intensive care medicine (a total duration of 2 years in the Netherlands, following their initial specialization in fields such as internal medicine or anesthesiology), while ‘intensivists’ refers to former fellows who have completed this intensive care training. Some other physicians, who work only temporarily in intensive care, also participated in the training program upon special request and when space was available. These participants will hereinafter be referred to as non-ICU physicians. Of all participants, 18 (hereinafter referred to as respondents) completed the questionnaire (response rate 32%). Among these respondents, 7 were intensivists, 7 were intensive care fellows and 4 were non-ICU physicians when they participated in the training.

Participant satisfaction

Table 3 presents participants' median ratings of the questionnaire statements for all respondents and per respondent category. In cases where the VR simulator was not operational due to a technical defect or when the tracheostomy training model was not yet available, participants did not score the related statements. While all but two statements received high median agreement scores of at least 4 across all respondent categories, indicating overall satisfaction with the training, there appeared to be a slight but not significant tendency for intensivists to rate some statements lower.

Open-ended questions

Analysis of the qualitative data from the open-ended questions revealed the following common themes:

1. **Good balance between theory and practice.**

Respondents appreciated the well-balanced combination of theory and practice in the training, as evidenced by the following statements:

> '[I liked] the alternation between practice and theory. Good basic information, applied to clinical cases. A lot of opportunities to practice on the training models with direct feedback'.

2. **Participants were satisfied with supervision.**

Respondents expressed satisfaction with the supervision provided during the training. They especially flagged the feedback from the simulator and support from the instructors as positives, as the following answers to the question 'What did you like about the training?' demonstrate:

> '[I liked] the supervision, that we got feedback from the simulator and good support from instructors'.

> '[I liked the] good supervision ... and good support from the instructors'.

Table 3: Respondents' questionnaire ratings of each item on a 5-point Likert scale.

Statement category	Statement	All (n = 18; median (IQR*))	Intensivist (n = 7; median (IQR))	Fellow intensivists (n = 7; median (IQR))	Non-ICU (n = 4; median (IQR))
General	I had sufficient time to practice	4 (4-5)	4 (3-4.5)	4 (4-5)	5 (4-NA**)
	The training made me feel more competent to perform future bronchoscopies	5 (4-5)	4 (4-4.5)	5 (4-5)	5 (5-5)
	The training prepared me well for performing future bronchoscopies in the intensive care suite	4 (4-5)	4 (4-4.5)	4 (4-5)	5 (5-5)
	If an intensivist wishes to receive bronchoscopy training, part of this training should be simulation-based	5 (4-5)	5 (4-5)	4 (4-5)	5 (5-5)
	On a scale of 1 to 5, how satisfied are you with the training?	4.5 (4-5)	4 (4-5)	4.5 (4-5)	5 (4-NA)
Training materials	The reading materials offered were relevant	4 (4-5)	4 (3.-4)	4 (3.8-5)	5 (5-5)
	The content of the presentations was relevant	4 (4-5)	4 (4-4)	4 (4-5)	5 (5-5)
	The content of the presentations was clear	4 (4-5)	4 (4-4)	4 (4-5)	5 (5-5)
	The presenting style of the presentations was clear	4 (4-5)	4 (4-4)	4 (4-5)	5 (5-5)
VR*** simulator	Operating the bronchoscope of the VR simulator was realistic	4 (4-5)	4 (4-4.5)	4.5 (4-5)	4 (3-NA)
	The anatomy depicted in the VR simulator was realistic	4 (4-5)	4 (4-4.5)	4.5 (4-5)	5 (4-NA)
	The VR simulator was relevant to learning to perform an inspection bronchoscopy	4 (4-5)	4 (4-4.5)	4.5 (4-5)	5 (4-NA)
3D bronchoscopy model	The anatomy of the 3D bronchoscopy model was realistic	4.5 (4-5)	4 (3-5)	4.5 (4-5)	5 (5-5)

Table 3: *Continued.*

Statement category	Statement	All (n = 18; median (IQR*))	Intensivist (n = 7; median (IQR))	Fellow intensivists (n = 7; median (IQR))	Non-ICU (n = 4; median (IQR))
	The 3D bronchoscopy model was relevant to learning to perform an inspection bronchoscopy	4 (4-5)	4 (3-5)	4 (4-5)	5 (5-5)
Simulated tracheostomy procedure	The simulated tracheostomy procedure was realistic	4 (4-5)	4 (4-4)	4 (3.8-5)	5 (4-NA)
	The simulated tracheostomy procedure was relevant to learning to perform a tracheostomy procedure under bronchoscopic guidance	4 (4-5)	4 (4-4)	4 (4-5)	5 (4-NA)
Competences	The training improved my bronchoscopy competences	4 (4-5)	4 (3.5-4.5)	4 (4-5)	5 (5-5)
	The training made me able to inspect all lobes and segments	4 (3.8–5)	3 (2.5-4.5)	4 (4-5)	5 (5-5)
Supervision	I am satisfied with the supervision received	5 (4-5)	4 (4-4.5)	5 (4-5)	5 (5-5)
	I am satisfied with the level of expertise of the instructors	5 (4-5)	4 (4-4.5)	5 (4-5)	5 (5-5)

1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree, 5 = strongly agree. * IQR = interquartile range. ** NA = not applicable, as the 75th percentile could not be calculated in some cases due to the limited sample size of the non-ICU group. *** VR = virtual reality. Three participants could not answer the questions about the VR simulator because it was not operational due to a technical defect, and 1 participant could not answer the questions about the tracheostomy model, as it was not yet available.

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3. Increased confidence and competence.

Respondents reported feeling more confident and competent to perform bronchoscopies in an intensive care setting as a result of the training. In their words:

> '[...] The anatomy is much clearer now. I feel more competent to perform a bronchoscopy'.

> 'I am more confident in performing the procedure'.

4. The training is recommendable.

All respondents stated that they would recommend the training to others, as the following answers demonstrate:

> 'Yes [I would recommend the training to others], I think everyone working in the ICU team should have participated in this course'.

> 'Yes [I would recommend the training to others], it was a good hands-on training program for non-pulmonologists who would like to perform bronchoscopies in the ICU'.

5. Positive perception of simulators.

Respondents expressed positive views about the simulators used in the training. They considered the VR simulator as relevant and enjoyable for practice, because of its built-in game-like tasks. Similarly, the 3D bronchoscopy model was perceived as relevant, as it allowed participants to practice interventions. The same held true for the tracheostomy simulation procedure. The following statements illustrate these positive perceptions:

> '[I liked] the content, structure and especially the simulation part of the training'.

> '[The VR simulator] was fun, very informative and challenging'.

> '[The 3D-printed bronchoscopy model is] convenient to work with. You can see what you are doing'.

> 'I liked it [the tracheostomy simulation procedure]. [It was a] realistic way of practicing. [The] simulation equipment [was] good. We practiced the entire procedure'.

6. No clear simulator preference.

Participants' responses did not point to a specific preference for a simulator when practicing inspection bronchoscopies. While some respondents (*n* = 6) equally liked both the 3D-printed bronchoscopy model and the VR simulator, others expressed a preference for either one. Those who preferred the VR simulator (*n* = 5) appreciated the immediate feedback it offered, whereas those who favored the 3D-printed bronchoscopy model (*n* = 4) perceived it as more realistic.

7. Desire for additional practice and skill refresher opportunities.

As points of improvement, respondents especially expressed a desire for more practice time and the opportunity to re-engage with parts of the training at a later time for skill enforcement. This desire was demonstrated by the answers to the question 'Do you see any opportunities for improving the training?':

> 'To have the option for revisiting the training at a later time'.
>
> 'More practice is always better'.
>
> 'For the retention of [the acquired skills], it would be beneficial to repeat the training after two months'.

Discussion

In this article, we described the development, implementation and evaluation of a 1-day simulation-based bronchoscopy training program for trainees and specialists working in an intensive care setting. To our knowledge, this study was the first describing the design of such a program specifically for intensivists. Evaluation outcomes demonstrated that participants were very satisfied with the training, as all questionnaire statements received a median score of at least 4 out of 5. The answers to the open-ended questions furthermore revealed that participants appreciated the supervision they received as well as the feedback from both simulators and instructors. They also valued the simulator equipment which they perceived as relevant. Finally, participants confirmed that they would recommend the training to colleagues.

Although no significant differences were observed in the survey results between the different participant categories, there appeared to be a trend towards intensivists rating statements somewhat lower compared to intensive care fellows and other physicians working in the ICU. This could likely be attributed to their past experiences with bronchoscopy procedures in the ICU, suggesting that the training program in its current form may be the most beneficial for physicians with less bronchoscopy experience. Therefore, we believe that tailoring the training content to different experience levels will most probably enhance overall participant satisfaction even more. This tailoring could be achieved by gauging participants' experience levels at the start of the training or by organizing separate training days for different experience levels.

The fact that participants appreciated the feedback from both simulators and instructors emphasizes the importance of keeping training groups small so as to create a safe learning environment in which participants have ample opportunity to practice. This reiterates prior qualitative research findings that limiting the number of participants in simulation-based bronchoscopy training contributes to a safe and positive learning environment [23]. Specifically, a group size of 4 is recommended, with a maximum of 6 participants. In our study, groups in the simulation sessions were even smaller, with 3 participants, which allowed for even more practice time than the recommended group size. Our evaluation outcomes also showed that participants favored simulators that were both fun (because containing playful learning or serious gaming) and realistic. Yet, previous research in other medical professions has revealed that such high-fidelity simulators (i.e., simulators with a high degree of realism) do not necessarily contribute to procedural skill improvement [24]. As only 1 study related to bronchoscopy was included in this review, we encourage researchers to examine the effects of simulator realism on skill transfer in the specific context of clinical bronchoscopy.

Despite the training program being valued by participants, we recognize some limitations. First, no formal instructional design theory was used when the training program was developed. The intensivists possessed a profound enthusiasm for the potential of simulation training to teach bronchoscopy skills to colleagues, but we recognize that certain fundamental principles of instructional design may not have been addressed, such as constructive alignment [25] and a thorough needs assessment [26]. Specifically, constructive alignment involves ensuring that all simulation activities are aligned with the learning objectives and that validated assessment methods (such as the Bronchoscopy Skills and Tasks Assessment Tool (BSTAT) [27]) are used that evaluate whether trainees have achieved these objectives. In our training program, while learning activities were aligned with the learning objectives, validated assessment methods to evaluate trainees' skills and knowledge were lacking. Additionally, the preliminary training program was developed without a thorough needs assessment: it lacked a tracheostomy simulation session, which was later added to the final program based on feedback of colleagues. A robust needs assessment would involve identifying bronchoscopy skill and knowledge gaps among intensivists before designing the initial training program, by gathering input from intensivists and other stakeholders like pulmonologists. This input should then inform the formulation of learning objectives. Using these instructional design principles from the start, might have resulted in a training program aligning more with educational theory, probably leading to better transfer to clinical practice. Second, a critical aspect of any training program is the formulation of specific and measurable learning objectives. In our case, these were not explicitly defined and evaluated from the beginning. Together with the absence of objective, quantitative evaluation measures to measure skill improvement, we believe that this limited our ability to demonstrate true training effectiveness. Third, the relatively low response rate of 32% to the survey may have introduced non-response bias, which could have affected our final results[28]. Additionally, it is worth noting that while a relatively large number of intensivists participated in the training (31 out of 57), only 7 completed the questionnaire. This limited response rate among intensivists may have led to a small overestimation of the overall positive evaluation of the training program, as their feedback, although not statistically significant, seemed slightly less favorable compared to other participants. Despite this limitation, we believe the positive feedback from all participants who responded highlights the program's potential. Finally, we did not pay any attention to the role of instructors in participant satisfaction with the training program. Investigating the impact of instructors on participant satisfaction might provide valuable insights for future study or program redesign.

In conclusion, our findings suggest that SBT can be a well-received tool to teach intensivists bronchoscopy skills. The program's content could be further enhanced by incorporating instructional design principles during the analysis and design phase of the training program and by tailoring the program to learners' needs. Furthermore, implementing a validated summative assessment such as the BSTAT and exploring the impact of instructors on the program's success is highly recommended. We therefore recommend intensivist educators to design future bronchoscopy simulation training programs according to a more evidence-based approach. Nevertheless, we believe that our comprehensive description of the program's development process and the evaluation results provided in this study can serve as a valuable resource for those wishing to establish similar training programs.

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Supplemental material 1: Questionnaire

Full questionnaire. Regarding the statements, 1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree, 5 = strongly agree.

What did you like about the training?

Do you see any opportunities for improving the training?

How relevant was the training for your (future) clinical practice?

Would you recommend the training to others? And why (not)?

General

I had sufficient time to practice	1	2	3	4	5
The training made me feel more competent to perform future bronchoscopies	1	2	3	4	5
The training prepared me well for performing	1	2	3	4	5
future bronchoscopies in the intensive care suite	1	2	3	4	5
If an intensivist wishes to receive bronchoscopy training, part of this training should be simulation-based	1	2	3	4	5
On a scale of 1 to 5, how satisfied are you with the training?	1	2	3	4	5

Training materials

The reading materials offered were relevant	1	2	3	4	5
The content of the presentations was relevant	1	2	3	4	5
The content of the presentations was clear	1	2	3	4	5
The presenting style of the presentations was clear	1	2	3	4	5

Do you have any comments regarding the abovementioned training materials?

Virtual Reality (VR) simulator

Operating the bronchoscope of the VR simulator was realistic	1	2	3	4	5
The anatomy depicted in the VR simulator was realistic	1	2	3	4	5
The VR simulator was relevant to learning to perform an inspection bronchoscopy	1	2	3	4	5

What did you think of the VR simulator?

3D bronchoscopy model

The anatomy of the 3D bronchoscopy model was realistic	1	2	3	4	5
The 3D bronchoscopy was relevant to learning to perform an inspection bronchoscopy	1	2	3	4	5

What did you think of the 3D bronchoscopy model?

Which of the two simulators did you prefer for practicing an inspection bronchoscopy: the 3D bronchoscopy model or the VR simulator? And why?

Which of the two aforementioned simulators did you prefer for practicing aspiration of sputum? And why?

Simulated tracheostomy procedure

The simulated tracheostomy procedure was realistic	1	2	3	4	5
The simulated tracheostomy procedure was relevant to learning to perform a tracheostomy procedure under bronchoscopy guidance	1	2	3	4	5

What did you think of the simulated tracheostomy procedure?

Competences

The training improved my bronchoscopy competences	1	2	3	4	5
The training made me able to inspect all lobes and segments	1	2	3	4	5
Supervision	1	2	3	4	5
I am satisfied with the supervision received	1	2	3	4	5
I am satisfied with the level of expertise of the instructors	1	2	3	4	5

Do you have any remarks regarding supervision?

Chapter 7

General discussion

A global consensus exists that simulation-based training (SBT), if implemented correctly, is a valuable tool for healthcare education and practice [1]. Specifically, in the field of flexible bronchoscopy (FB) education, previous reviews have demonstrated that SBT may lead to positive learning outcomes [2,3]. However, many of the included studies were low-powered or included participants who were not representative of the pulmonology resident population. Moreover, ethical and practical constraints often resulted in the use of pretest-posttest designs, which are considered less robust compared to other research designs such as randomized controlled trials [4]. As a result, a lack of comprehensive evidence still exists on the effectiveness of bronchoscopy SBT when introduced in formal training curricula and applied in real-life training settings. This thesis aimed to address these limitations by exploring different aspects of bronchoscopy SBT. In this final chapter, the main findings of the studies conducted in this thesis are discussed, along with general considerations regarding the nationwide implementation of the FB SBT program in the Netherlands. Additionally, suggestions for educators, researchers and policymakers are provided, followed by a discussion of the strengths and limitations of this thesis and suggestions for future research.

Summary of the studies in this thesis

In **Chapter 2**, the results of a systematic literature review on the effectiveness of FB SBT were reported. The findings indicated that FB SBT is an effective method for teaching bronchoscopy to novice residents. However, the included studies were low-powered, conducted in single-center settings, and effectiveness on patient outcome data was lacking. This underscores the need for future studies investigating the effectiveness of FB SBT within formal training curricula and real-world training settings. Ideally, these studies should evaluate outcomes at Kirkpatrick level 3 and 4, assessing behavioral changes in clinical practice and subsequent patient outcomes, respectively [5]. Additionally, the review identified two key training features associated with training effectiveness: integrating the training program in the curriculum and using simulation tasks with varying difficulty levels.

In **Chapter 3**, the potential pretesting effect in FB SBT was explored in two types of simulated environments: a non-anatomical environment (NAE), where anatomical structures are irrelevant (e.g., a digital maze in which the operator must maneuver the bronchoscope to follow a blue ball), and an anatomical environment (AE), which realistically represents bronchial anatomy and requires trainees to apply their anatomical knowledge. The results showed no pretesting effect on overall bronchoscopy competence (i.e., a combination of scope handling and anatomy knowledge) in an AE. However, a significant pretesting effect was observed for procedure time in both a NAE and AE. In the NAE, a significant pretesting effect was also observed for the number of wall contacts, but this effect disappeared after controlling for procedure time. These findings suggest that procedure time and wall contacts should not be used as primary outcome measures for evaluating the effectiveness of FB SBT interventions. FB educators should also keep this in mind when selecting assessment methods, to ensure reliable evaluation of residents' bronchoscopy proficiency. Preferably, residents should be assessed with validated performance assessment tools.

In **Chapter 4**, the development and validation of a theoretical bronchoscopy entry exam were described, using Kane's validity framework as a guiding structure. The expert-guided development, together with acceptable item difficulty, item discrimination, and internal consistency, supported the exams' validity. Moreover, based on instructor feedback and passing rates, the results showed that both exams effectively motivated residents to prepare for bronchoscopy simulation-based training, highlighting the value of knowledge assessments in ensuring thorough preparation and allowing more simulation-based training time to be focused on mastering procedural skills.

Chapter 5 demonstrated the effectiveness of a FB SBT program that was implemented on a nationwide scale in real-life training settings in the Netherlands, involving 100 residents. The training program focused on developing basic bronchoscopy skills, specifically the ability to navigate the bronchoscope with proper dexterity and accurately identify and enter all airway segments. In a basic, non-anatomical simulated environment, nearly all simulator metrics showed significant improvement. Moreover, in an anatomically realistic simulated environment, residents demonstrated improved basic bronchoscopy skills, as evidenced by a significant improvement in overall-competence scores and scope handling ratings, as evaluated by a blinded expert. As such, this study provides a valuable contribution to existing research, showing that FB SBT is effective when implemented in a nationwide real-life training setting. Based on these findings, residency training programs should incorporate mandatory SBT before allowing residents to perform bronchoscopies on real patients.

In **Chapter 6**, the development, implementation and evaluation of an FB SBT program for intensive care fellows and intensivists were discussed. The results indicated that FB SBT is highly valued by intensivists, who appreciated the simulators being both engaging and realistic. However, although the training program was highly valued, we recognize that its effectiveness and scientific foundation could have been improved by incorporating instructional design principles from the start and by employing summative assessment methods. Therefore, clinicians planning to set up an FB SBT program are strongly encouraged to involve educational experts early in the process to ensure optimal learning outcomes.

Considerations regarding the nationally implemented FB SBT program

Until recently, bronchoscopy training in the Netherlands followed the traditional apprenticeship model, where residents acquire their skills by performing the procedure on patients under supervision [6]. However, with the advent of simulators, bronchoscopy educators in the Netherlands determined that allowing inexperienced residents to practice on real patients was no longer ethically justifiable. As a result, the Dutch Association of Chest Physicians (NVALT) decided to make bronchoscopy SBT mandatory as the first step in the bronchoscopy training pathway for pulmonology residents.

A working group was established, consisting of 12 Dutch pulmonology experts, one simulation expert and one educational expert from 6 different centers. Their aim was to design a mandatory FB SBT program for Dutch first-year pulmonology residents. Two international experts were also consulted to reach consensus on the program. The resulting program, described in **Chapter 5**, aligned closely with Merrill's First Principles of Instruction [7], as it incorporated real-world problems, activation of prior knowledge, demonstration of new knowledge, application of new skills and integration of these skills into clinical practice. Residents engaged in realistic bronchoscopy tasks, activated prior knowledge acquired through a theoretical entry exam, and received demonstrations and feedback from experienced pulmonologists. They applied their skills in simulated bronchoscopy scenarios and were encouraged to integrate these skills into their clinical practice, by performing clinical bronchoscopies once they had completed the training program.

Significant attention was also given to faculty development. International pulmonology training guidelines emphasize that the effectiveness of SBT not only depends on the simulator itself, but also on the expertise of the faculty providing the training [8]. Therefore, a faculty document outlining the training program was developed (Supplemental material 1), and regular online meetings with all faculty members were held before and after the program's implementation.

Additionally, interventional pulmonology guidelines state that SBT should be preceded by a theoretical stage [9]. Accordingly, the working group deemed it essential for residents to establish a strong theoretical foundation before commencing bronchoscopy training. Specifically, the group emphasized the importance of sufficient anatomical knowledge, as gaps in this area could significantly slow down the learning process during SBT. Therefore, a theoretical bronchoscopy exam was developed, consisting of two parts: one assessing knowledge on topics such as (contra-)indications, local anesthetics, sedation procedures, and the second focused on anatomy. For the latter, residents were required to answer all questions correctly to ensure no time would be lost during the SBT due to inadequate anatomical knowledge.

The implemented training program also presented an interesting opportunity for research. The systematic literature review in **Chapter 2** revealed that most FB SBT studies were conducted in small, single-center settings. Examining the impact of the Dutch nationally implemented training program in real-life training settings, with its large expected number of participants due to its mandatory nature and the involvement of numerous faculty members, provided a valuable opportunity to study its effects and make thus an important contribution to existing literature. This study, described in **Chapter 5**, followed a pretest-posttest design, as ethical considerations and the mandatory nature of the training program precluded the use of other designs such as randomized controlled trials. Such trials would have required withholding SBT from some residents, which would mean they practiced their first bronchoscopy skills on real patients without prior SBT. The pretest-posttest design, while practical, is less robust than other designs because performing a pretest might contribute to improvements observed in the posttest, a phenomenon known as the pretest effect. However, the study described in **Chapter 3** demonstrated that no such effect was present for the primary outcome measure used in **Chapter 5**: overall-competence scores on an observational basic bronchoscopy assessment tool. The study in **Chapter 5** demonstrated that, after following a one-day FB SBT, residents' bronchoscopic competence levels could improve significantly, with median overall-competence scores rising from a novice level to a competent level. By contrast, within the apprenticeship method, residents can sometimes take up to three months to reach a comparable level of competence. Moreover, this SBT program avoided exposing patients to inexperienced and unskilled residents, which could lead to unnecessarily prolonged procedure times and increased patient discomfort due to more bronchial wall contacts during the procedure. Additionally, it was observed during the training that residents' prior knowledge of anatomy proved highly valuable. This knowledge ensured the training proceeded smoothly, although no specific data on this aspect was collected.

Recommendations for setting up (FB) SBT programs

Based on the findings in this thesis, we propose the following recommendations for the successful design and implementation of FB SBT programs:

1. Involve faculty and educational experts early in the process.

Engaging faculty and stakeholders from the start is essential for successful implementation. In the nationally implemented FB SBT program, early involvement of faculty helped establish a shared understanding of the training objectives and content. Regular online meetings were held post-implementation to monitor the training process, address challenges and ensure consistency.

In Chapter 6, the retrospective evaluation of the intensivist FB SBT program highlighted the importance of engaging educational experts early in the course design process. While participants valued the program, the absence of educational expert input during the design phase may have resulted in a less evidence-based approach. Constructive alignment, an important principle in educational design [10] was absent. This principle ensures that learning activities and assessments are aligned with intended objectives, optimizing the efficiency and effectiveness of training programs.

In contrast, the nationally implemented FB SBT program benefited from the involvement of educational and simulation-based education experts during its design phase, which ensured the integration of constructive alignment. The first learning objective focused on developing residents' dexterity in navigating the bronchial tree with proper scope handling. This required deliberate movements in the vertical plane (Y-axis), combined with rotation (X-axis) and flexion/deflexion (Z-axis) of the bronchoscope tip (Figure 1), while explicitly discouraging horizontal plane movements and excessive scope bending, which do not contribute to effective navigation. These specific parameters were emphasized during the training and integrated into both the simulator tasks and assessment tools. The second objective required residents to enter and identify all airway segments adequately. Again, the simulator tasks were intentionally chosen to target this objective, and the assessment methods incorporated parameters to evaluate whether residents met it. Through the alignment of the training objectives with simulator tasks and assessment methods, the nationally implemented FB SBT program had a coherent and evidence-based design, demonstrating the value of early involvement of experts in the field of (simulation-based) education.

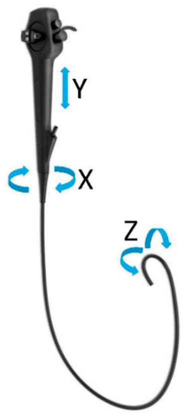

Figure 1: Illustration of the bronchoscope with the X, Y, and Z movements. Adapted with permission from Innovex Medical from: https://www.endotx.com.au/product/innovex-single-use-flexible-bronchoscope/.

To our surprise, we found very few studies about simulation-based training initiatives where the authors explicitly discussed the involvement of educational experts in the design of the training program. One notable exception was a study that mentioned the involvement of experts in education in designing an SBT curriculum for upper gastrointestinal endoscopy [11]. This curriculum was developed using a validated, stepwise approach by a multidisciplinary task force, which included experts in gastrointestinal simulation, endoscopy, and simulation-based education. This approach led to a well-structured, proficiency-based, standardized training program.

Although the design phase of the nationally implemented FB SBT program included one education expert and one simulation expert, residents from the intended training population were absent. The inclusion of learners in the design process, often referred to as co-creation, can enhance both the quality of training programs and learner motivation [12]. Despite its potential benefits, to our knowledge, no studies have investigated the involvement of residents in the design phase of FB SBT programs.

2. Provide training for faculty and schedule regular meetings.

Effective faculty training is essential for the success of SBT programs and is widely regarded as a key strategy to enhance their effectiveness [1]. Faculty development ensures that instructors not only possess the technical expertise to utilize SBT technologies effectively, but also learn how to provide constructive feedback and maintain consistency in instruction and assessment, which are critical for improving the success of SBT programs. Indeed, research in colorectal laparoscopy SBT has demonstrated that a structured faculty training curriculum improved the learning curve of trainees [13]. Additionally, faculty training plays a critical role in addressing a major challenge in SBT: trainers who are experts in performing procedures such as endoscopies, often operate with unconscious competence in their skills. This can make it difficult for them to break down technical skills and effectively teach those to residents. Faculty training supports trainers in transitioning to conscious competence, enabling them to explain each step of the procedure clearly [14].

Furthermore, regarding the nationally implemented FB SBT program, we strongly believe that the regular meetings held after its implementation have significantly contributed to the consistency of how the training was delivered. Therefore, we recommend scheduling regular meetings with al involved faculty to discuss how they have been managing the training, whether they have encountered any challenges and ensure alignment in how the training is conducted.

3. Introduce entry exams to ensure adequate preparation for simulation-based training.

A preceding theoretical stage is essential to ensure the efficiency of FB SBT programs. Insufficient anatomical knowledge can hinder the training process. Therefore, educators should consider administering theoretical exams to ensure residents have adequate foundational knowledge before participating in training programs. A notable example of effective theoretical exam design to complement SBT can be found in endoscopy training, where a summative exam has been implemented to assess trainees' endoscopic knowledge and skills. General surgery training applicants are required to successfully complete this exam, which comprises a theoretical multiple-choice component and a simulator-based technical skills assessment [15]. Both components underwent rigorous validity testing to ensure reliability. Regarding the theoretical exam, detailed item analyses of expert-designed questions were conducted, resulting in a highly reliable exam with an extensive amount of validity evidence [16].

4. Use standardized assessment tools and ensure continuous validation.

Chapter 3 showed that residents should be assessed in anatomically realistic environments. Novices can quickly learn to 'cheat' non-anatomical simulated environments and demonstrate significant improvements in simulator metrics, such as fewer wall contacts and a reduced procedure time, without corresponding improvements in anatomy knowledge or scope handling dexterity. While training in non-anatomical environments can complement the learning experience, their simulator metrics should not be used as primary assessment measures, as they may not reflect clinical competence accurately.

In **Chapter 2**, we emphasized the importance of assessing residents using previously validated and homogeneous assessment methods. However, the widely used Bronchoscopy Skills and Task Assessment Tool (BSTAT) [17], developed by Bronchoscopy International, includes an item assessing the resident's ability to describe secretions, which makes it unsuitable for use in an SBT setting. Additionally, the tool contains items evaluating the resident's ability to perform interventions such as bronchoalveolar lavage and biopsies, making it inappropriate for assessing basic bronchoscopy skills. While the BSTAT is often regarded as a gold standard in bronchoscopy assessment, its inconsistent use across FB SBT studies, with different studies employing different versions [18–20], limits the comparability of study outcomes.

In **Chapter 5**, we therefore used a previously validated assessment tool [21], but modifications were necessary to adapt it to our simulation procedure. These adaptations, however, complicate comparisons between our study and those using the original tool, which represents a notable limitation. This highlights the need for basic bronchoscopy assessment tools that can be applied across various simulators, contexts and training programs, without requiring modifications. We believe that our adapted assessment tool contributes to this need, as it is specifically designed to assess basic bronchoscopy skills, namely the residents' ability to navigate the bronchoscope with proper dexterity and accurately identify and enter all airway segments. It focuses solely on scope insertion, hand and wrist movements, controlled scope movements and bronchial segment identification and entering – all of which are applicable across different bronchoscopy simulators. We have already compared the tool's results to blinded expert ratings of scope handling, and another study is underway to further investigate the validity of this tool in assessing basic bronchoscopy skills.

At the same time, validity is not a fixed feature; a tool is not simply valid or invalid [22,23]. Instead, it depends on context and requires ongoing evidence collection across different settings. Therefore, if a tool has been validated in one setting, its validity cannot automatically be assumed in another. Future studies should aim to gather validity evidence for assessment tools across different contexts, such as with varying simulators or trainee populations. Additionally, it is important to determine when modifications to a tool, such as fine-tuning it for a specific simulation setting or learning goals, are substantial enough to require new validity evidence to be collected. Ensuring this will help maintain the reliability of assessment methods in FB SBT.

Additionally, since the suggested assessment methods still rely on expert judgment, it is essential to prioritize investigating which metrics derived from a simulator are clinically relevant, as these could offer an objective reflection of performance and potentially reduce the reliance on subjective expert evaluation.

5. Mandate SBT in bronchoscopy education.

SBT should be a mandatory component of bronchoscopy training. **Chapter 5** demonstrated that FB SBT is a very effective tool to teach bronchoscopy skills to novice residents, also when implemented in a nationwide setting across multiple centers in real-life training settings. The results showed that residents can acquire the ability to navigate the bronchoscope with proper dexterity and to accurately identify and enter all airway segments within a single day in a simulation setting, significantly accelerating the learning curve compared to traditional methods. This approach reduces the burden on patients, as residents perform faster, more accurate bronchoscopies after completing SBT, compared to practicing their first bronchoscopies on patients. Policymakers play an important role in mandating FB SBT, by creating regulations that integrate SBT into bronchoscopy education. Otherwise, some educators may continue relying solely on traditional patient-based training methods, overlooking the value of simulators.

Additionally, frequent practice in a clinical setting is necessary to maintain competency after SBT [24]. However, if the frequency of clinical bronchoscopies is too low, skill decay may occur. Two bronchoscopy simulation studies have demonstrated significant simulated skill decay within 2 months after SBT [19,25]. It is likely that the same applies to bronchoscopic skills acquired in clinical practice if procedures are performed too infrequently. SBT could help refresh these skills, and implementing mandatory refresher courses for pulmonologists may be a worthwhile approach when the number of performed clinical bronchoscopies falls below a certain threshold.

While this thesis primarily focused on simulation-based training for basic bronchoscopy, more advanced bronchoscopic procedures such as endobronchial ultrasound-guided transbronchial needle aspiration (EBUS-TBNA) could also possibly benefit from simulation. Given the long learning curve of this procedure [26], simulation may be valuable for skill acquisition and maintenance. For example, one study demonstrated that SBT was superior to the traditional apprenticeship training method for acquiring EBUS-TBNA skills [26]. Guidelines also recommend simulation-based EBUS-TBNA training [27], and the European Respiratory Society has developed an EBUS-TBNA training course including SBT [28]. Given the benefits of mandatory simulation-based training for basic bronchoscopy, it is worth considering whether SBT should also be a required component of EBUS-TBNA training.

Strengths and limitations of this thesis

The studies presented in this thesis have several notable strengths. First, the pretest-posttest study was the first to explore a pretest effect in an FB SBT, providing a valuable contribution to existing research. While most studies follow a pretest-posttest design, none had explored the existence of a pretest effect, let alone corrected for it. Second, the study on the impact of the nationwide program on residents' skills is the first to demonstrate the effectiveness of FB SBT when implemented in real-world training settings. With 100 residents participating, this represents the largest study of its kind to our knowledge. Furthermore, evaluations by a blinded expert confirmed the demonstrated improvements in dexterity, a step often neglected in previous studies.

Despite these strengths, the studies in this thesis also have limitations. A notable limitation of is the lack of data on the effectiveness of FB SBT on data measures in a patient setting. In Chapter 2, we emphasized the critical need for future research assessing the impact of FB SBT on outcomes measured at Kirkpatrick level 3 and 4, which measure behavioral changes in clinical settings and patient outcomes, respectively [5]. However, the study examining the nationwide implementation of the FB SBT training program in the Netherlands relied solely on outcomes measured on Kirkpatrick level 2, i.e. skill improvement in a simulated environment. Unfortunately, logistical and ethical challenges made conducting a clinical follow-up study infeasible. Specifically, requiring raters to travel nationwide to assess residents' clinical bronchoscopy performance would have been infeasible, as many residents work in hospitals different from those where the raters are based. Another limitation might be the pretest-posttest design we used. However, the mandatory and nationwide nature of our training program precluded the use of a randomized design.

Suggestions for future research

This thesis primarily focused on FB SBT using high-fidelity simulation. Although high-fidelity simulators offer a realistic training setting for residents with a high level of interactivity, they are expensive and therefore not always accessible in every training environment. In such cases, low-fidelity simulators could serve as a reasonable alternative. Indeed, previous research [19] has shown that self-directed training by medical students on a low-cost 3D-printed airway model led to significantly improved modified BSTAT scores. However, since only one study to date has evaluated the effectiveness of basic FB training on a low-fidelity simulator, and no studies have compared the effectiveness of low- versus high-fidelity simulators for such training, it remains unclear whether high-fidelity simulation is superior to low-fidelity simulation. To make meaningful comparisons, the intended learning objectives should be clearly defined beforehand, as these should guide the selection of both the instructional methods and the level of simulator fidelity to be used. Which level of fidelity is most suitable likely depends on these objectives. Investigating the effectiveness of FB SBT programs that do not rely on expensive high-end simulators could therefore be a valuable direction for future research. If feasible, we also recommend comparing their effectiveness with bronchoscopy SBT using high-fidelity simulators.

Additionally, current assessments rely heavily on expert involvement, which is time-consuming and susceptible to rater bias. In **Chapter 5**, blinded expert evaluations were required to confirm on-the-spot ratings and assess improvements in dexterity. An alternative approach could be the use of motion analysis, as previous research has shown that motion data from simulated bronchoscopies correlates with the experience level of bronchoscopists [29]. Another study highlighted the potential of motion data to objectively assess motor skills in bronchoscopy [30]. These findings suggest that motion data could serve as an objective measure to assess dexterity, potentially reducing reliance on expert judgment and supporting more standardized assessment approaches in the future.

Beyond motion analysis, artificial intelligence (AI) may also offer new possibilities for assessment with reduced reliance on experts. One study has shown promising validity evidence for AI-based assessment of anatomical and navigational bronchoscopy competence in a simulation setting [31]. The study reported significant correlations between AI-based outcomes of anatomical and navigational competence and expert ratings of anatomy and dexterity, suggesting that AI could help standardize evaluations of FB skills while reducing the need for expert involvement. The study by Colt et al [31], however, does not specify which AI approach was used (e.g., large language models or machine learning). Given the potential for real-time assessment, machine learning seems to present a greater opportunity for bronchoscopy SBT, potentially providing efficient and scalable evaluation methods. However, an important limitation is that the AI system in the study by Colt et al [31] did not directly assess dexterity. While AI scores correlated with expert-rated dexterity outcomes, these ratings were based only on wall collisions, red-out and scope centering, without evaluating hand, wrist and arm movements. As a result, AI-based assessment may not yet be sufficient for training proper hand, wrist and arm movements, meaning expert guidance will likely remain essential for developing these skills in the coming years. If expert involvement remains necessary, their input might also be used to directly train trainees in anatomy and navigation skills rather than relying on AI-based assessments for these aspects.

Another unexplored area of research is the potential of tele-mentoring in FB SBT. A study in laparoscopy SBT [32] demonstrated the feasibility and effectiveness of tele-mentoring in improving basic surgical skills. Applying tele-mentoring to FB SBT could enable pulmonology residents to receive real-time feedback and guidance from remote experts, reducing the need for on-site expert supervision. A promising application could be allowing trainees to practice on a low-fidelity simulator at their convenience, followed by expert feedback via tele-mentoring at a scheduled time. This approach would be especially beneficial for regions with limited resources, where access to high-fidelity simulators and experienced faculty is often constrained.

Finally, the absence of data in this thesis on the effectiveness of our FB SBT program in improving residents' performance during their first bronchoscopies on real patients highlights a common challenge in simulation research, where practical and ethical constraints often preclude the inclusion of such data [33]. Nonetheless, the findings presented in this thesis underscore the significant value of simulation-based training in improving bronchoscopy competence. While the lack of outcome data in a real patient setting is a limitation, it does not, in our view, justify a return to the traditional apprenticeship model, which we regard as highly unethical given the strong evidence presented in **Chapter 5**. To gain a more comprehensive understanding of the impact of FB SBT, we recommend that future studies prioritize generating outcome data in real patient settings. One potential strategy is to design longitudinal studies in patient settings with fewer logistical challenges. Addressing these issues would enable future studies to provide even more robust evidence for the effectiveness of FB SBT in improving both resident performance and patient care outcomes.

Final conclusions

This thesis demonstrated that simulation-based training is a very effective method to teach flexible bronchoscopy skills to residents, also when implemented on a nationwide scale in real-life training settings. In a one-day training program, it was possible to bring almost all of our residents from a novice to a competent level in performing a basic diagnostic bronchoscopy. Our findings suggest that simulation-based training should be a mandatory first component of flexible bronchoscopy education. Furthermore, this thesis provided valuable recommendations for researchers, educators and policymakers aiming to design or implement simulation-based training programs.

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Supplemental material 1: Outline bronchoscopy simulation-based training program

09:00 – 10:00: Introduction by the pulmonologist and pretest

- Brief recap of anatomy by the pulmonologist using the anatomy poster, instructions on scope handling and use of Simbionix simulator.
- Pretest**:** Participants record demographic information such as age, gender, and gaming experience (on a separate form). They perform Task 1 on the simulator once, without receiving any feedback from the pulmonologist. Then, they complete Task 1 five times on the simulator. After each run, the pulmonologist records the following outcome measures:

  A) Percentage of time in mid-lumen
  B) Number of wall contacts
  C) Time per run
  D) Percentage of time the scope is in contact with the wall

Next, the pulmonologist demonstrates the beginning of Task 2 once, stopping when the first question mark appears, to briefly illustrate expectations. The participant then performs Task 2 in full, systematically naming and numbering the segments (from 1 to 10). The Basic bronchoscopy assessment tool (BBAT) is used for evaluation.

10:00 – 12:00: Anatomy & scope handling practice under supervision

- Participants practice Task 1 on the simulator
- Participants practice Task 2 on the simulator

12:00 – 13:00: Lunch

13:00 – 15:00: patient cases, and scope handling practice under supervision

- Participants complete patient cases 1, 2, 3, 4, 5, and/or 6 on the simulator, avoiding wall contacts while identifying anatomical structures in the involved segments, diagnosing, and performing sampling with the appropriate tools.
- Participants practice Tasks 1 and 2 in preparation for the posttest.

15:00 – 16:00: Posttest

- **Posttest:** Participants complete Task 1 five times and Task 2 once on the simulator. The instructor records the same data as in the pretest.

Impact

Introduction

Flexible bronchoscopy is a procedure in which a doctor, often a pulmonologist, introduces a flexible tube through the patient's mouth or nose to inspect the airways. It is a crucial procedure for diagnosing and treating various pulmonary diseases, such as infections and lung cancer. Because an incorrectly performed bronchoscopy can be very uncomfortable for patients and may compromise their safety, bronchoscopy education is a fundamental part of pulmonology training. Traditionally, trainees performed their first bronchoscopies on real patients under the supervision of an experienced pulmonologist. However, this approach often caused patient discomfort and increased the risk of complications. Over the last two decades simulation-based training has emerged as a safer alternative, allowing trainees to develop bronchoscopy skills in a controlled environment without any risks for patients.

Study aims and results in this thesis

This thesis first identified the gaps in the current scientific knowledge regarding the effectiveness of flexible bronchoscopy simulation-based training. In **Chapter 2,** a systematic literature review was presented, demonstrating that flexible bronchoscopy simulation-based training appeared to be an effective tool, however prior studies tended to be low-powered and conducted in single-center settings. This review also identified two training features that appeared to correlate with training effectiveness: integrating the training program in the curriculum and using simulation tasks with varying levels of difficulty. **Chapter 3** explored whether performing a pretest on a bronchoscopy simulator could improve trainees' posttest scores, in the absence of simulation-based training (the pretest effect). The findings showed that a pretest effect exists regarding reductions in procedure time and the number of wall contacts, suggesting that observed improvements in trainees' procedure time and the number of wall contacts on a bronchoscopy simulator can possibly be due to their familiarity with the testing procedure on the simulator.

In 2020, a one-day mandatory simulation-based training program was implemented in the Netherlands for all novice pulmonology trainees. **Chapter 4** investigated the validity of the theoretical pre-test that trainees were required to complete before participating in the training program. This study found that the pretest provided a solid knowledge foundation, effectively preparing trainees for the practical training. To address the limited data on the effectiveness of flexible bronchoscopy simulation-based training when implemented on a large nationwide scale, the study presented in **Chapter 5** evaluated this aspect. This study demonstrated significant improvements in pre-training and post-training assessments of basic bronchoscopy skills, confirming that, at a nationwide level, simulation-based training can rapidly advance trainees from a novice level to a competent level in basic bronchoscopy skills within a single day. This is something that would otherwise take months, depending on clinical exposure to diagnostic bronchoscopies.

Lastly, **Chapter 6** extended the scope of this thesis from pulmonology trainees to intensive care trainees and professionals, who occasionally perform bronchoscopies. This study underscored the value of simulation-based training for those health care professionals as well and highlighted the importance of involving educational experts early in designing such programs to improve their effectiveness.

Contribution of the findings to postgraduate medical education, science and society

The findings in this thesis make a significant contribution to postgraduate medical education. The introduction of mandatory simulation-based bronchoscopy training for novice trainees has led to a standardized, controlled learning environment that facilitated the rapid development of essential bronchoscopy skills. Simulation-based training reduces the time it takes for trainees to reach a competent level in basic bronchoscopy skills, something that would normally take several months when trainees practice in a clinical setting. These results suggest that simulation-based training initiatives could be a valuable addition to postgraduate medical education curricula, offering a standardized training approach that is less dependent on clinical exposure and, moreover, ensuring that trainees are better prepared to perform procedures on real patients. Better preparation through simulation-based training also improves residents' self-efficacy, which in turn reduces stress during procedures and improves their overall confidence when working with real patients.

The studies presented in this thesis also make significant contributions to science and society. The systematic review in **Chapter 2** identified a lack of high-quality evidence on the effectiveness of bronchoscopy simulation-based training, as many prior studies were limited to small, single-center settings. Additionally, the study in **Chapter 3** is the first to assess the pretest effect in bronchoscopy simulation-based training research. This study has important implications for other bronchoscopy simulation studies, since it underscores the importance of refraining from solely using procedure time and the number of wall contacts as major outcome measures. Instead, studies should at least also use a measure to evaluate navigational skills, such as validated performance assessment tool end scores.

The findings in **Chapter 5** demonstrated that novice trainees can achieve substantial skill improvements in a single day of structured simulation-based training, even when implemented on a national level across multiple centers with many trainers. As such, this study provided an important contribution to science and daily training practice of pulmonology trainees, demonstrating that simulation-based training really is an effective method not only in strictly regulated research settings but also in real-world training settings. Therefore, these findings must also have consequences on a societal level. As bronchoscopy simulation-based training accelerates the learning curve of novice pulmonology trainees, ensuring that they are better prepared before performing bronchoscopies on real patients, bronchoscopy simulation training should be mandatory for all novice pulmonology trainees.

Relevance to target groups

The findings in this thesis support the adoption of simulation-based training before trainees perform bronchoscopies on patients. Given our results, allowing residents to practice their initial bronchoscopy skills on real patients should now be considered ethically unacceptable.

Policy makers involved in developing bronchoscopy training programs should therefore now consider implementing regulations that require simulation-based bronchoscopy training as a prerequisite before residents are allowed to improve their bronchoscopy competencies while performing bronchoscopies on real patients. Additionally, the findings of the pretest effect study should encourage educators to focus on valid assessment measures beyond procedure time and simulator metrics when assessing trainees' competence. These insights are equally important for anyone involved in bronchoscopy research, as they serve as guidelines for evaluating training programs.

Finally, these findings benefit will patients as well. Where patients previously might have faced the risk of undergoing bronchoscopies performed by inexperienced trainees, simulation-based training ensures that trainees will have already practiced their skills in a safe environment and will have reached at least a competent level in basic bronchoscopy. This provides patients with greater reassurance about the quality of the care they receive.

Dissemination of our findings

The studies presented in this thesis were submitted to and published in peer-reviewed scientific journals. Their results were also presented at the DSSH conference (2022), the ERS Congress (2022 and 2023), the Dutch NVMO conference (2023), and the SESAM annual meeting (2024). Additionally, I was interviewed for the CHEST Journal podcast, which is available on most podcast platforms and has the potential to reach a wide audience. Finally, a simulated bronchoscopy training is featured in the Maastricht University Science Stories video series, aimed at lay people, where I emphasize the effectiveness of bronchoscopy simulation-based training and its role in ensuring the safety of bronchoscopies performed by novice Dutch pulmonology trainees.

Summaries

Summary

Flexible bronchoscopy is an essential diagnostic and therapeutic procedure for various pulmonary diseases, such as infections and lung cancer. While generally perceived as safe, the procedure can cause discomfort for patients and, in rare cases, lead to life-threatening complications. To minimize patient risks, bronchoscopy education is a fundamental part of pulmonology training. Traditionally, bronchoscopy skills were taught using the apprenticeship model, but this approach was associated with increased procedure duration, scope damage and complications. Simulation-based training has emerged as an alternative training method, allowing pulmonology residents to practice bronchoscopy skills in a stress-free environment without compromising patient safety. This thesis explored key aspects of flexible bronchoscopy simulation-based training, including its effectiveness in real-world training settings, the suitability of outcome and assessment measures, the role of theoretical pretests in preparing residents, and lessons learned for designing effective training programs.

Chapter 2 presented a systematic literature review on the effectiveness of flexible bronchoscopy simulation-based training and their instructional features. The findings indicated that flexible bronchoscopy simulation-based training is effective in improving bronchoscopy skills among novices, but included studies were low-powered, conducted in single-center settings, and lacked data on patient outcomes. Two key training features associated with training effectiveness were identified: integrating the training program in the curriculum and using simulation tasks with varying difficulty levels.

Chapter 3 investigated the potential influence of the pretest effect on outcome measures commonly used in flexible bronchoscopy simulation-based training. The study found that a pretest effect exists regarding procedure time and the number of wall contacts. No pretest effect was found for overall bronchoscopy competence. These results underscore the importance of selecting reliable assessment methods such as validated observational assessment tools.

In **Chapter 4**, the development and validation of an anatomy and theoretical bronchoscopy exam was described, using Kane's validity framework as a guiding structure. The expert-guided development, together with acceptable item difficulty, item discrimination and internal consistency supported the exams' validity. Moreover, based on instructor feedback and passing rates, the results showed that both exams effectively motivated residents to prepare for bronchoscopy simulation-based training, highlighting the value of knowledge assessments in ensuring thorough preparation and allowing more simulation-based training time to be focused on mastering procedural skills.

In **Chapter 5** the effectiveness of a mandatory, one-day flexible bronchoscopy simulation-based training program for novice pulmonology residents in the Netherlands was evaluated. This large-scale study demonstrated significant improvements in basic bronchoscopy competence. In a basic navigation task, simulator-generated metrics improved significantly, but more importantly, in an anatomically realistic environment, procedure time was halved and residents' level of basic bronchoscopic competence went from a novice to a competent level. These findings confirm the effectiveness of flexible bronchoscopy simulation-based training when implemented in real-world training settings.

Chapter 6 extended the scope from pulmonology residents to intensive care fellows and professionals. The study demonstrated that flexible bronchoscopy simulation-based training was highly valued by those healthcare professionals. Additionally, the study highlighted the importance of incorporating educational design principles and involving educational experts during the design of simulation-based training programs, providing valuable insights for educators planning similar initiatives.

Nederlandse samenvatting

Flexibele bronchoscopie is een essentiële diagnostische en therapeutische procedure voor uiteenlopende longaandoeningen zoals infecties en longkanker. Hoewel een flexibele bronchoscopie over het algemeen als een veilige procedure wordt beschouwd, kan het ondergaan ervan ongemak veroorzaken bij de patiënt en in zeldzame gevallen leiden tot levensbedreigende complicaties. Om risico's voor de patiënt te verkleinen, is bronchoscopieonderwijs een essentieel onderdeel van de opleiding van longartsen. Traditioneel werden bronchoscopievaardigheden aangeleerd via de meester-gezelmethode, maar deze trainingsmethode ging gepaard met een langere proceduretijd, schade aan de bronchoscoop en een verhoogd risico op complicaties. Inmiddels wordt simulatietraining beschouwd als een veelbelovende alternatieve methode, waarbij longartsen in opleiding hun bronchoscopievaardigheden in een stressvrije omgeving kunnen oefenen, zonder dat de patiëntveiligheid in het geding komt. In dit proefschrift werden belangrijke aspecten van simulatietraining voor flexibele bronchoscopie onderzocht, waaronder de effectiviteit ervan in de praktijk, de geschiktheid van uitkomst- en beoordelingsmaten, en de rol van theoretische pretoetsen bij het voorbereiden van longartsen in opleiding op simulatietraining. Daarnaast biedt dit proefschrift belangrijke inzichten voor het ontwerpen en implementeren van effectieve trainingsprogramma's.

Hoofdstuk 2 beschreef een systematisch literatuuronderzoek naar de effectiviteit van simulatietraining voor flexibele bronchoscopie en de bijbehorende didactische kenmerken. De resultaten toonden aan dat simulatieonderwijs effectief is in het verbeteren van bronchoscopievaardigheden bij beginners, maar de geïncludeerde studies hadden kleine steekproeven, waren uitgevoerd binnen de context van één centrum en bevatten vaak geen gegevens over patiëntuitkomsten. Twee trainingskenmerken bleken samen te hangen met effectiviteit: het integreren van het trainingsprogramma in het curriculum en het gebruik van simulatietaken met verschillende moeilijkheidsniveaus.

Hoofdstuk 3 beschrijft het onderzoek naar de mogelijke impact van het pre-toetseffect op veelgebruikte uitkomstmaten in simulatietraining voor flexibele bronchoscopie. De studie toonde aan dat er een pre-toetseffect bestaat voor proceduretijd en de hoeveelheid wandcontacten. Er werd geen pre-toetseffect gevonden voor algemene bronchoscopiecompetentie. Deze bevindingen onderstrepen het belang van het selecteren van betrouwbare beoordelingsmethoden, zoals gevalideerde observatie-instrumenten.

In **Hoofdstuk 4** werd de ontwikkeling en validatie van een bronchiale anatomietoets en een toets over theoretische kennis van bronchoscopie beschreven, met Kane's validiteitskader als leidraad. De toetsvragen werden ontwikkeld door experts. De validiteit van de toetsen werd mede ondersteund door een acceptabele interne consistentie, een passend moeilijkheidsniveau en voldoende mate van onderscheidend vermogen. Daarnaast bleek uit feedback van instructeurs en slagingspercentages dat beide toetsen longartsen in opleiding effectief motiveerden om zich voor te bereiden op bronchoscopie-simulatietraining. Dit onderstreept de waarde van kennistoetsen om een grondige voorbereiding te waarborgen en zo meer tijd tijdens de simulatietraining beschikbaar te houden voor het aanleren van procedurele vaardigheden.

In **Hoofdstuk 5** werd de effectiviteit van een verplichte, eendaagse simulatietraining in flexibele bronchoscopie voor beginnende longartsen in opleiding in Nederland geëvalueerd. Deze grootschalige studie liet significante verbeteringen zien in de basisvaardigheden voor bronchoscopie. In een eenvoudige navigatietaak verbeterden simulatie-gegenereerde uitkomstmaten aanzienlijk. Bovendien halveerde in een anatomische realistische taak de proceduretijd, en gingen de bronchoscopievaardigheden van de longartsen in opleiding van beginnend naar een competent niveau. Deze bevindingen bevestigen de effectiviteit van simulatietraining die geïmplementeerd wordt in de praktijk op grote schaal.

In **Hoofdstuk 6** werd de reikwijdte van het onderzoek verbreed van longartsen in opleiding naar intensivisten (zowel in opleiding als ervaren). De studie liet zien dat simulatietraining voor flexibele bronchoscopie zeer gewaardeerd werd door deze groepen. Daarnaast benadrukte de studie het belang van het toepassen van onderwijskundige ontwerpprincipes en het betrekken van onderwijskundigen bij de ontwikkeling van simulatieonderwijs, wat waardevolle inzichten biedt voor opleiders die vergelijkbare initiatieven willen opzetten.

Addendum

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About the author

Eveline Charlotte Françoise Gerretsen was born on May 17, 1998, in Hengelo, Overijssel, the Netherlands. During high school, she developed a strong interest in health and healthcare, driven by a deep curiosity about the human body. This interest led her to pursue a bachelor's degree in Biomedical Sciences at Maastricht University, which she started in 2015. After her first year, she chose the Molecular Life Sciences track, focusing on the biological processes at the molecular and cellular level. Her graduation internship was in the field of bioinformatics.

To broaden her perspective beyond molecular-level human biology, Eveline went on to pursue the research master's program in Biomedical Sciences at Radboud University in Nijmegen in 2018. This program offered a broad curriculum, ranging from cancer biology to toxicology and cardiovascular physiology, as well as courses in policy, communication and qualitative research.

During her master's program, she completed two research internships, both in laboratory settings. During the second internship, she realized that while she enjoyed doing research, she preferred to work outside of a lab environment. In 2020, she began her PhD project on simulation-based bronchoscopy training at the School of Health Professions Education (SHE) in Maastricht.

Currently, Eveline works at the Maastricht University Medical Center+ as part of the DUTCH consortium (Digital United Training Concepts for Healthcare). She serves as a project coordinator for the Faculty Development program, supporting educators involved in simulation-based training for anesthesia assistants, radiologic technologists and operating room staff.

List of publications

Publications included in this thesis

Gerretsen EC, Chen A, Annema JT, Groenier M, van der Heijden EH, van Mook WN, et al. Effectiveness of Flexible Bronchoscopy Simulation-Based Training: A Systematic Review. Chest. 2023;164(4):952-62.

Gerretsen EC, Groenier M, Annema J, Heijden EH, van Mook WN, Aldenkamp AF, et al. Basic Bronchoscopy Competence Achieved by a Nationwide One-day Simulation-based Training. J Bronchology Interv Pulmonol. 2025;32(1):e0995.

Gerretsen EC, Popeijus HE, Annema JT, Clementsen PF, Corbetta L, Gompelmann D, et al. Development and Validation of two Bronchoscopy Knowledge Assessments. Respiration. 2025.

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van Wilpe S, **Gerretsen EC**, van der Heijden AG, de Vries IJM, Gerritsen WR, Mehra N. Prognostic and Predictive Value of Tumor-Infiltrating Immune Cells in Urothelial Cancer of the Bladder. Cancers (Basel). 2020;12(9):2692.

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