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Automatic and Objective Assessment of Motor Skills Performance in Flexible Bronchoscopy

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Keywords
Flexible bronchoscopy · Bronchoscopy education · Assessment tool · Motion analysis system · Simulation

Abstract
Background: Motor skills have been identified as a useful measure to evaluate competency in bronchoscopy. However, no automatic assessment system of motor skills with a clear pass/fail criterion in flexible bronchoscopy exists. ***Objectives:*** The objective of the study was to develop an objective and automatic measure of motor skills in bronchoscopy and set a pass/fail criterion. ***Methods:*** Participants conducted 3 bronchoscopies each in a simulated setting. They were equipped with a Myo Armband that measured lower arm movements through an inertial measurement unit, and hand and finger motions through electromyography sensors. These measures were composed into an objective and automatic composite score of motor skills, the motor bronchoscopy skills score (MoBSS). ***Results:*** Twelve novices, eleven intermediates, and ten expert bronchoscopy operators participated, resulting in 99 procedures available for assessment. MoBSS was correlated with a higher diagnostic completeness (Pearson's correlation, $r = 0.43$, $p < 0.001$) and a lower procedure time (Pearson's correlation, $r = -0.90$, $p < 0.001$). MoBSS was able to differentiate operator performance based on the experience level (one-way ANOVA, $p < 0.001$). Using the contrasting groups' method, a passing score of −0.08 MoBSS was defined that failed 30/36 (83%) novice, 5/33 (15%) intermediate, and 1/30 (3%) expert procedures. ***Conclusions:*** MoBSS can be used as an automatic and unbiased assessment tool for motor skills performance in flexible bronchoscopy. MoBSS has the potential to generate automatic feedback to help guide trainees toward expert performance.

Introduction

Flexible bronchoscopy is an essential part of pulmonary medicine, with the majority of respiratory physicians trained in the procedure [1]. Traditionally, training follows the apprenticeship model, where the trainee per-

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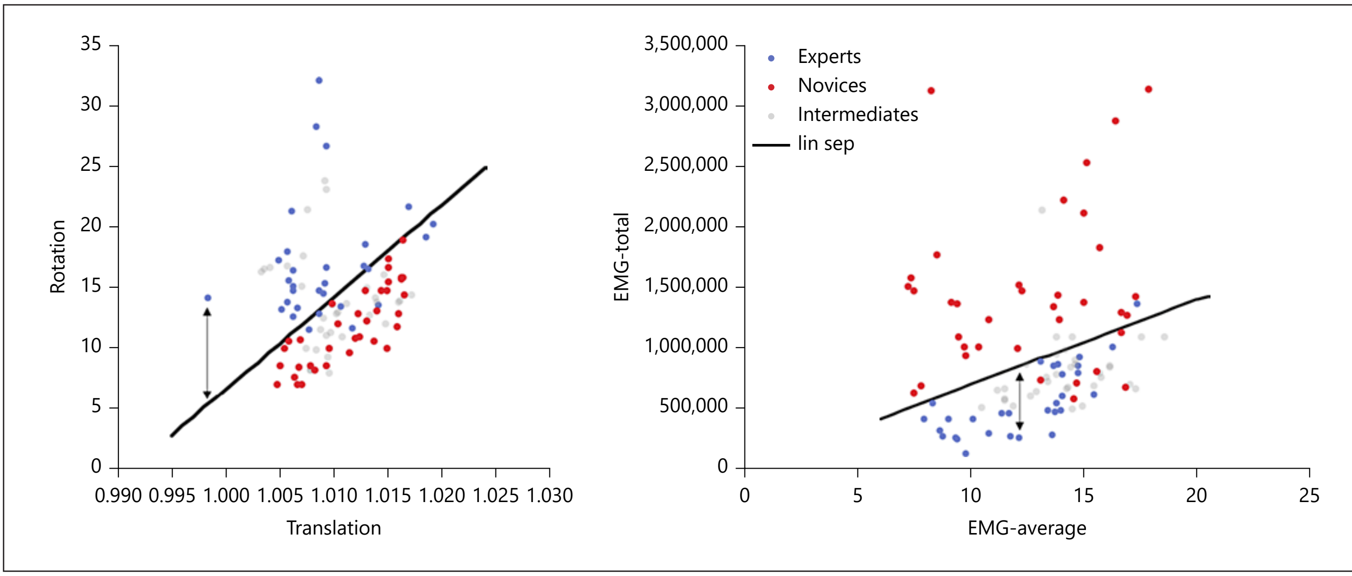

Fig. 1. Left: IMU score was composed from translation (movement in the *XYZ* plane) and rotation (pronation and supination). IMU score was calculated as the vertical distance to the separation line (green line – online version). Being above the line resulted in a positive score. Right: EMG score was composed from EMG average and EMG integral. EMG score was calculated as the vertical distance to the separation line. Being below the line resulted in a negative score. EMG, electromyography; IMU, inertial measurement unit.

forms the procedure supervised by a senior colleague. This teaching approach exposes patients to unnecessary risks such as higher complication rates, higher amount of sedation used, and longer procedure times (PT) [2–5]. Simulation-based practice in bronchoscopy is effective and allows for training of procedural skills away from the patients [6]. One study showed superior performance among novices trained in simulation as compared to the traditional approach [7]. Simulation provides an opportunity for mastery learning, allowing trainees to practice until criteria for proficiency are met and before progressing to perform supervised invasive procedures on patients [8, 9]. Reliable and valid assessment instruments are available to evaluate the trainee's performance after simulation-based mastery learning in flexible bronchoscopy [10]. However, these assessment tools do not account for motor skills through scope handling, which has been identified as a useful measure of competence [11]. Additionally, example-based learning is practiced in simulation, where an expert demonstrates a step of the procedure, for example, scope handling, to a trainee and provides feedback. This reduces cognitive load and improves learning outcome in bronchoscopy [12] and reduces the risk of learning wrong techniques during unsupervised practice [13, 14]. However, example-based learning does not relieve senior colleagues from time constraints, and techniques may differ from expert to expert in terms of teaching and providing feedback. This role could be augmented and potentially replaced by automatic assessment of motor skills based on objective criteria. While automatic assessment has been used to measure competency in bronchoscopy [11], it relies on extensive setup, may not be transferable to a clinical setting, and does not provide a passing score for correct scope handling.

Aim of the Study

The aim of this study was to develop an automatic and objective assessment instrument to evaluate motor skills when performing flexible bronchoscopy, to investigate the validity of the assessment instrument, and to define a pass/fail criterion for motor skills when conducting a complete flexible bronchoscopy in a simulation-based setting.

Materials and Methods

Study Design and Setting

A prospective comparative study was conducted in a simulated setting. An endoscopy tower with a flexible bronchoscope (EVIS Exera II and Q180 flexible bronchoscope, Olympus, Japan) was used to inspect a phantom equipped with a three-dimensional bronchial tree (CLA Broncho Boy, CLA, Coburg, Germany). The

Myo Armband (MA) (Thalmic Labs, ON, Canada) was used to measure total movement of the lower arm through an inertial measurement unit (IMU) and total movement of the hand and fingers through electromyography (EMG). The MA has been investigated for a variety of applications such as hand hygiene training [15], rehabilitation therapy [16–18], and successfully distinguishing experience levels in laparoscopic knot tying [19]. Validity investigation of the tool was performed using Messick's validity framework (Table 1) [20], as recommended by the American Educational Research Association when evaluating validity [21, 22].

Development of a Motor Skills Score: Content

With the hypothesis that the MA can be used to assess motor skills without any a priori assumption of what is correct scope handling, we developed the motor bronchoscopy skills score (MoBSS) as a composite score based on the IMU and EMG. The separation lines mentioned for the below datasets were established as modified linear regressions with the intent of separating novices and experienced groups. The datasets are defined in the following text.

Translation, Rotation, and IMU Score

The score was based on an accelerometer that quantified the movements in the XYZ plane (left/right, front/back, and up/down directions), referred to as translation, and a gyroscope that quantified rotation of the lower arm, referred to as rotation. Data for translation and rotation were continuously logged through the procedures (see online suppl. 1; for all online suppl. material, see www.karger.com/doi/10.1159/000513433). These parameters were summarized as an average to eliminate time bias as novices tend to take longer time than experts. These 2 data sources were composed into a composite score of total lower arm movement referred to as the IMU score, by establishing a separating line in the 2 data source dimensions (Fig. 1). The IMU score was calculated as residuals, the vertical distance to the separating line (Fig. 1). Having a score above the line resulted in a positive score and below the line in a negative score.

EMG Outcomes (Average, Integral, and Score)

Data from the 8 EMG sensors of the MA were logged (online suppl. 2). The sensors provided metrics of motion of wrist and fingers by measuring muscle activity in the forearm. The outcome parameters for EMG were set to be average EMG usage (EMG average) and total EMG usage (EMG integral). EMG average and EMG integral were generated into a composite score, the EMG score, by a separation line, similar to the IMU score, except being below the separation line resulted in a positive score (Fig. 1).

Motor Bronchoscopy Skills Score

The EMG score and the IMU score were calculated to generate a composite score, MoBSS. The score was composed using Pythagorean addition, where the score of each measure is squared to make all scores, representing a measure, positive before addition. The choice to use the Euclidean distance (Pythagorean addition) is the analogy to summarize coordinates as a distance, rather than summarizing the locations. An analogy is position on a map, having 2 positions makes little sense to add but can be summarized as a distance by Pythagorean addition. The sign of the EMG score was used to maintain the separation arising from the EMG score. The choice of sign (EMG), and not sign (IMU), was a subjective design consideration. It is needed for the summarizing score as the residuals for novices and experienced are reversed for IMU and EMG scores, respectively (Fig. 1).

Color version available online

Fig. 2. Experimental setup with the participant performing a full bronchoscopy while wearing the Myo Armband and the first author performing a live rating.

MoBSS=sign(EMG-_score)×√(⟦(EMG-score)⟧)^2+(⟦(IMU-score)⟧^2)

MoBSS measures scope handling and can potentially be used as an assessment tool, based on measures for movement of the lower arm (IMU score) and movement of the hand and fingers (EMG score).

Participants

Informed consent was obtained prior to inclusion along with self-reported bronchoscopy experience: total procedures performed, procedures performed as bronchoscopy training in a simulated setting, procedures performed within the last 12 months, and days since the last procedure. The participants were divided into 3 groups based on their level of experience as the total amount of procedures performed, as follows:

Novices: Physicians with no prior experience in flexible bronchoscopy.

Intermediates: Physicians who had performed 5–100 bronchoscopies.

Experts: Physicians who had performed >500 bronchoscopies.

Ethical approval is not required for studies not concerning patients according to Danish law and was therefore not obtained.

Assessment Procedure

At least 2 days prior to inclusion, the participants received a basic handbook in flexible bronchoscopy as an introduction to the procedure, anatomy of the bronchial tree, and how to systematically visualize all segments [23]. Assessment was conducted individually and consisted of a pretrial and a test.

Pretrial

Each participant located 4 marks in a makeshift box using the bronchoscope. The MA was positioned on the participant's arm

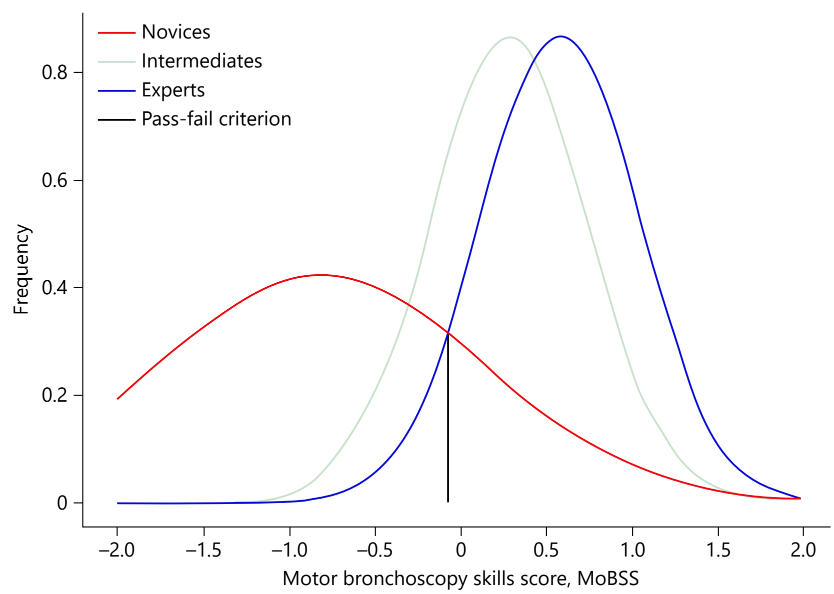

Fig. 3. Contrasting groups' method for MoBSS. The pass/fail criterion is set at −0.08 MoBSS which fails 30/36 novice (83%), 5/33 (15%) intermediate, and 1/30 (3%) expert procedures. MoBSS, motor bronchoscopy skills score.

holding the bronchoscope with the MA logo on the radial side to margo anterior, as an indicator of uniform placement on all participants, standing in the anatomically neutral position (Fig. 2).

Test

Each participant performed 3 complete bronchoscopies and was instructed to enter all segmental bronchi with the tip of the endoscope. No feedback was given.

Rating of Participants' Performance

Checklist-Rating

Each participant was live-rated by the first author (K.C., Fig. 2) during the procedure using a checklist that was set up in a graphical user interface, the Tkinter library written in Python (Python Software Foundation, Python Language Reference, version 3.7.6) (Fig. 3). The first author (KC) verified all recordings for the correct number of visited bronchi. Based on the checklist, we were able to report the following established outcome measures [24, 25]:

Diagnostic Completeness: It is the fraction of visited bronchial segments.

Procedure Time: It is the time from passing through the vocal cords to retraction of the scope.

Data Analysis and Statistics

For correlation between MoBSS and diagnostic completeness (DC) and PT, Pearson's correlation coefficient r was used. The performance scores collected through MA (translation, rotation, IMU score; EMG average; EMG integral; EMG score; and MoBSS) were compared using one-tailed, one-way ANOVA as it was assumed novices would not show superior movements to experts. To set a pass/fail criterion for MoBSS, the contrasting groups' method was used [26].

All data analyses were completed in Python (3.7.6, Python Software Foundation), using libraries SciPy [27], Matplotlib [28], and NumPy [29]. Statistical testing was completed in SPSS version 25 (PASW v25.0; SPSS Inc., Chicago, IL, USA). A p value <0.05 was considered statistically significant.

Results

Totally 12 novices, 11 intermediates, and 10 experts were enrolled. Every participant performed 3 bronchoscopies, resulting in 99 procedures. Validity evidence for the 5 sources is summarized in Table 1.

MoBSS correlated positively with DC (Pearson's correlation, $r = 0.43$, $p < 0.001$) and inversely with PT (Pearson's correlation, $r = -0.90$, $p < 0.001$). This correlation was still significant when analyzing only the expert group: MoBSS with DC (Pearson's correlation, $r = 0.41$, $p = 0.02$) and MoBSS with PT (Pearson's correlation, $r = -0.58$, $p <$ 0.001) (Table 3).

ANOVA found significant differences for MoBSS ($p <$ 0.001) and all other subscores (Table 2). The contrasting groups' method was used to define a pass/fail criterion for motor skills [26]. The pass/fail criterion was defined at −0.08 that failed 30/36 (83%) novice, 5/33 (15%) intermediate, and 1/30 (3%) expert procedures (Fig. 3).

Table 1. Different sources of validity evidence for MoBSS based on Messick's validity framework[a]

Source of evidence for validity and description	Validity evidence for MoBSS
Content: The test content should measure what it is supposed to measure	A pulmonary consultant with >20-year experience in bronchoscopy (PC) hypothesized, along with a thoracic surgeon and professor of medical education (LK), that the Myo Armband automatically could assess motor skills in bronchoscopy. The MoBSS was generated by a biomedical engineer with >5-year experience in simulation (MS), based on an IMU score and EMG score, thereby measuring total movements of the lower arm, hand, and fingers
Response process: Integrity of data should be maintained at all times. Test administration should be controlled or standardized at a maximum level possible	All procedures were performed in a controlled, simulated environment, making the tests comparable as they were performed wearing the same Myo Armband with the same scope on the same phantom. For data integrity, all recordings were blinded and double-checked for correct amount of visited bronchi with the video recordings by the primary investigator (KC)
Internal structure: This refers to the reliability of the test results. Test-retest reliability measure consistency in operator performance between the procedures	The test-retest reliability was high for MoBSS with a Cronbach's alpha = 0.86
Relation to other variables: Assessment scores should correlate with known measures of competence – MoBSS should correlate with known measures of competence, for example, experience level	MoBSS correlated positively with DC (Pearson's correlation, $r = 0.43$, $p < 0.001$) and inversely with PT (Pearson's correlation, $r = -0.90$, $p < 0.001$). ANOVA found significant differences with linearity for translation ($p = 0.026$), rotation ($p < 0.001$), IMU score ($p < 0.001$), EMG integral ($p < 0.001$), EMG score ($p < 0.001$), MoBSS ($p < 0.001$), structured progress ($p < 0.001$), and PT ($p < 0.001$). For EMG average, ANOVA found significant differences ($p = 0.01$) without linearity ($p = 0.89$) between the groups
Consequence: Consequences of testing relates to the pass/fail standard that is set	The contrasting groups' method set the pass/fail score at –0.08 MoBSS, which failed 30/36 novice, 5/33 intermediate, and 1/30 expert procedures, resulting in 6 false-positives and 1 false-negative

PT, procedure time; EMG, electromyography; IMU, inertial measurement unit; DC, diagnostic completeness; MoBSS, motor bronchoscopy skills score. [a] Messick S. Validity: In: Linn RL, editors. *Educational measurement*. 3rd ed. New York: American Council on Education and Macmillan; 1989. pp 13–104.

Discussion

This is the first study to use both the IMU and EMG for motor skills analysis in flexible bronchoscopy with a pass/fail criterion. MoBSS is a progressive score that can differentiate between novice, intermediate, and expert skill levels and correlates positively with the previous established outcome measure DC and inversely with PT.

Moving the scope in the XY plane does not translate into a movement of the tip of the scope. Therefore, these movements can be regarded as redundant movements. In the clinical setting, redundant movements of the bronchoscope will prolong PT and add to the "wear and tear" of the operator and the bronchoscope. Furthermore, redundant movements cause increased wear and tear of the bronchoscope and as well as increased physical stress of the operator's muscles and joints. People who are skilled at a task will therefore limit unnecessary movements [14]. This is in accordance with our study since the expert group scored the lowest for translation, indicating less movement of the scope in the XYZ plane. This also aligns with a previous study that assessed bronchoscopy skills by differentiating the skill level based on a preset criterion as total scope deviation from a straight line, stating that the scope should only move in the Z direction (up and down direction) [11]. However, Colella and coauthors [11] focused on the scope, instead of operator movements, and had a setup not transferable to a clinical setting. Our study focused on operator movements without any a priori assumption of what is correct scope handling.

The expert group scored higher for rotation, indicating more movements of supination and pronation. An-

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Table 2. Group comparison for motor scores, DC, and PT

Variable	Novice procedures (n = 36)	Intermediate procedures (n = 33)	Expert procedures (n = 30)	p value[a]	Post hoc test[b]
Translation[c]	1.14±0.40	0.99±0.36	0.90±0.44	0.03	C
Rotation	11.90±3.24	13.90±3.86	16.98±4.92	<0.001	A, B, C
IMU score	−0.22±0.12	0.04±0.41	0.34±0.49	<0.001	A, B, C
EMG average	12.57±3.43	14.17±1.97	13.04±2.85	0.01	A, B
EMG integral[d]	14.48±6.68	8.19±2.99	5.59±2.89	<0.001	A, B, C
EMG score	−0.76±0.94	0.17±0.31	0.37±0.24	<0.001	A, B, C
MoBSS	−0.81±0.94	0.28±0.46	0.58±0.46	<0.001	A, B, C
DC	0.79±0.12	0.85±0.11	0.91±0.06	<0.001	A, B, C
PT	520±265	240±53	211±80	<0.001	A, C

Values are presented as mean ± standard deviation. Number (n) indicates the amount of procedures. Post hoc A indicates statistical significance between novices and intermediates. Post hoc B indicates statistical significance between intermediates and experts. Post hoc C indicates statistical significance between novices and experts. DC, diagnostic completeness (number of visualized segments divided by the total number of segments); PT, procedure time (time from passage through the vocal cords to end of procedure in seconds); EMG, electromyography; IMU, inertial measurement unit; MoBSS, motor bronchoscopy skills score. [a] p value was calculated using a one-way, one-tailed Welch-ANOVA. [b] Indicates the result of the pairwise group comparison by a Games-Howell post hoc test. [c] The data are minus gravity times 100 to make them fit the table. [d] The data are divided by 10^5 to make them fit the table.

Table 3. Comparison between the newly developed MoBSS and existing bronchoscopy performance scores

Variable	Novice procedures (n = 36)	Intermediate procedures (n = 33)	Expert procedures (n = 30)	Total procedures (n = 99)
MoBSS versus DC	0.21	0.12	0.41	0.43
	0.22	0.53	0.02	<0.001
MoBSS versus PT	−0.98	0.07	−0.58	−0.90
	<0.001	0.70	<0.001	<0.001

Values are presented as Pearson's correlation coefficient and p value. p value was compared with Pearson's correlation. Number (n) indicates amount of procedures. DC, diagnostic completeness. Number of visualized segments divided by total number of segments; PT, procedure time. Time from passage through the vocal cords to retraction of the scope in seconds; MoBSS, motor bronchoscopy skills score.

other study explored the ergonomics of simulation-based bronchoscopy training and found that muscle usage decreases and ergonomic scoring improves as bronchoscopy experience increases [30]. This was shown in our study where the expert group scored lower for EMG integral.

The expert group scored higher for EMG average than the novice group, indicating more average muscle activity, but not in comparison with the intermediate group. This is the only motion parameter that did not show linearity between the groups (Table 2). The MA is useful in pattern recognition of hand and finger motions as flexion, extension, supination, pronation, etc. [31]. We were not able to translate the data into a specific set of hand motions and thereby identify if certain hand motions were significant among the groups.

MoBSS holds the potential to generate automatic feedback to the trainees during practice, potentially improving the learning outcome [32]. Motor skills analysis can be used to measure dexterity [33], and feedback with regard to this measure has proven its importance in other endoscopic tasks. In laparoscopy, individual and continuous motion feedback improves motion economy and operation time and decreases the path length traveled by the instruments [34].

DC and PT have been identified as measures of competence in flexible bronchoscopy [24, 25]. We found that MoBSS correlated with a higher DC and with a lower PT (Table 3). These findings hold an obvious confounder as MoBSS correlates with the experience level. When analyzing only the expert group, MoBSS still correlated positively with DC (Pearson's correlation, r = 0.41, p = 0.02) and inversely with PT (Pearson's correlation, r = –0.58, p < 0.001). This indicates that the experts possessing the best motor skills, as by MoBSS, performed the tasks faster and were able to visit more bronchial segments. This is on a par with findings for other endoscopic specialties. In both gastroscopy and colonoscopy, motion tracking-based measures correlate to the skill level [35–37].

Competency should be evaluated through skill acquisition with clear pass/fail criteria, that is, mastery learning [38]. Therefore, the method used in this study provides a pass/fail criterion with a clear training objective that can be part of combining several assessment tools as combining different methods improves the assessment of competence [39]. A passing score can be evaluated by its false-positive and false-negative rates. The passing score of –0.08 has a low false-positive rate as only 6/36 (17%) novice procedures passed and a lower false-negatives rate as only 1/30 (3%) expert procedure failed. The passing score can be regarded as too low as it allows for operators with no experience in scope handling to pass. Since performance is objectively measured, optimal scope handling could have been achieved intuitively or by chance, resulting in 6/30 novices passing. Importantly, "pass" in the present context does not mean that the novice can proceed and perform a real bronchoscopy but only that the novice had a steady hand and the ability to visualize the different segments of a phantom and thus can "pass" to the next step of learning bronchoscopy. Scope handling can be seen as just one of many steps in a much larger procedure of patient care including patient communication and solving a clinical problem. The difference in procedure-specific conditions of the phantom and a real bronchial tree can also explain why one expert without previous experience with phantom bronchoscopy failed the first and passed the 2 subsequent procedures.

It is important to establish validity evidence when evaluating an assessment tool to support its intended use [20]. We were able to evaluate MoBSS according to all 5 aspects of Messick's validity framework and set a pass/fail criterion that can help guide learners toward better motor skills in bronchoscopy.

Our study is the first to both use IMU and EMG for motor skills analysis in bronchoscopy with a passing score but still holds some limitations. Inclusion of more participants in different simulation centers would have made our findings more generalizable; however, our sample size was the largest reported to date for this kind of study (99 procedures), and the size was sufficient to show significant group differences and comparable to other educational studies [40]. The participant groups were divided according to procedural experience, which as stated is not a guarantee of competence, even though the expert group performed significantly better than the 2 other groups. However, not all experts inspected all segments, and MoBSS correlated positively with DC (Pearson's correlation, r = 0.41, p = 0.02). This is in line with a previous study when testing experienced operators in a simulation-based setting [24]. Therefore, experienced operators should be tested before being labeled as experts, and future studies should classify the groups according to tested performance, instead of experience levels. Our study was conducted in a simulated setting, and we did not test for transferability to a clinical setting. In bronchoscopy, a study has shown simulation-based training to be superior to traditional clinical training among novices and translates into enhanced patient care [41]. Learning correct scope handling is a prerequisite for performing bronchoscopies in patients, and MoBSS could help guide trainees in this manner. Future studies should therefore examine how using MoBSS transfers into bronchoscopy performance in a clinical setting.

Conclusion

Our novel assessment tool (MoBSS) was able to discriminate between novices and experts with a credible passing score and correlated with previous established measures of competence. Thus, MoBSS can be used as an automatic and unbiased assessment measure for motor skills performance in flexible bronchoscopy and has the potential to generate automatic feedback to help guide trainees toward expert performance.

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Statement of Ethics

Ethical approval is not required for studies not concerning patients according to Danish law and was therefore not obtained.

Conflict of Interest Statement

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Author Contributions

Conceptualization and design: K.M.C., M.B.S.S., L.J.N., U.B., P.F.C., and L.K. Administrative support: U.B., P.F.C., and L.K. Provision of study materials: K.M.C. Collection and assembly of data: K.M.C. and M.B.S.S. Data analysis and interpretation: K.M.C. and M.B.S.S. Manuscript writing: all authors. Final approval of manuscript: all authors.

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