Interventional Pulmonology

Respiration

Respiration 2021;100:530–537
DOI: 10.1159/000514627

Received: October 31, 2020
Accepted: January 11, 2021
Published online: April 13, 2021

Variable Learning Curve of Basic Rigid Bronchoscopy in Trainees

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Keywords

Rigid bronchoscopy · Learning · Learning curve · Trainees · Competency

Abstract

Background: Despite increased use of rigid bronchoscopy (RB) for therapeutic indications and recommendations from professional societies to use performance-based competency, an assessment tool has not been utilized to measure the competency of trainees to perform RB in clinical settings. ***Objectives:*** The aim of the study was to evaluate a previously developed assessment tool – *Rigid Bronchoscopy Tool for Assessment of Skills and Competence* (RIGID-TASC) – for determining the RB learning curve of interventional pulmonary (IP) trainees in the clinical setting and explore the variability of learning curve of trainees. ***Methods:*** IP fellows at 4 institutions were enrolled. After preclinical simulation training, all RBs performed in patients were scored by faculty using RIGID-TASC until competency threshold was achieved. Competency threshold was defined as unassisted RB intubation and navigation through the central airways on 3 consecutive patients at the first attempt with a minimum score of 89. A regression-based model was devised to construct and compare the learning curves. ***Results:*** Twelve IP fellows performed 178 RBs. Trainees reached the competency threshold between 5 and 24 RBs, with a median of 15 RBs (95% CI, 6–21). There were differences among trainees in learning curve parameters including starting point, slope, and inflection point, as demonstrated by the curve-fitting model. Subtasks that required the highest number of procedures (median = 10) to gain competency included ability to intubate at the first attempt and intubation time of <60 s. ***Conclusions:*** Trainees acquire RB skills at a variable pace, and RIGID-TASC can be used to assess learning curve of IP trainees in clinical settings.

Introduction

Rigid bronchoscopy (RB) has seen an increased role in the management of malignant and nonmalignant central airway disorders [1, 2]. The rigid bronchoscope is a surgical instrument which can perform debulking, dilation, hemostasis, and other therapeutic functions, all while se-

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curing a safe airway for ventilation and providing a conduit for intraluminal devices such as flexible bronchoscopes, balloons, stents, and ablative therapies. Thus, RB has rightfully become the cornerstone of interventional pulmonary (IP) training.

Despite its increased utilization, there are limited data regarding the slope and variability of the RB learning curve. The importance of this gap has been further accentuated with the proliferation of IP training programs in the USA and worldwide [3], along with the inclusion and emphasis on RB training in many otolaryngology and thoracic surgery programs [4–6]. Without robust evidence, professional organizations including the American Thoracic Society (ATS), European Respiratory Society, and American College of Chest Physicians (ACCP) have recommended a 20-procedure threshold for achieving RB competency [7–9], albeit with the recognition that such numeric-threshold criteria for competency are fraught with limitations [6]. In addition, research in flexible bronchoscopy (FB) and endobronchial ultrasound training has shown that learners acquire skills at different paces [10, 11].

We have previously developed the *Rigid Bronchoscopy Tool for Assessment of Skills and Competence* (RIGID-TASC), an assessment tool to evaluate RB intubation and airway navigation skills [12]. It is a 23-point checklist-based assessment tool that evaluates RB intubation and airway navigation by an operator. RIGID-TASC was demonstrated to have validity in discriminating the RB skills of novice, intermediate, and expert operators in a manikin, with a high inter-rater reliability. We thus hypothesized that

1. The RIGID-TASC can be used to effectively measure and plot the RB skill acquisition curve of IP trainees undergoing clinical training to the point where they achieve a predefined basic competency threshold.
2. The skill acquisition curve of RB learners will have markedly different slopes and variations, highlighting the necessity of competence-based testing, as opposed to adherence to volume-based criteria.

Methods

In this prospective, multicenter study, twelve novice IP fellows at 4 US training programs were recruited and scored using the RIGID-TASC while performing RB as part of their clinical training. All RBs performed by the trainees were supervised and scored by a faculty interventional pulmonologist, starting with their initial procedure at the beginning of training, until the criteria for basic competency threshold were achieved. This basic competency threshold was defined as successful RB intubation and central airway navigation at the first attempt, without a supervisor's help, with a minimum score of 89/100, on 3 consecutive procedures. The third consecutive successful procedure was recorded as the procedure when competency was achieved. The score of 89/100 was chosen as it was shown to be the minimum score attained by the expert group of rigid bronchoscopists during the initial validation study [12]. In order to control for and exclude the confounding effects of anatomic variability of patients and a "lucky" accidental high score, we required 3 consecutive 89/100 scores. Since not all patients required every element of RB tested by the RIGID-TASC (e.g., navigation of mainstem bronchi in patients with tracheal stenosis or tumors), the score percentage was calculated from the clinically necessary, completed subtasks. IRB approval was obtained at all respective institutions: Duke University (Pro00055274), Virginia Commonwealth University (HM20002272), Johns Hopkins University (00139179), and Emory University (00075805). Informed consent was obtained from the participating IP fellows; participation of the fellows was voluntary with no bearing on their fellowship training or evaluations.

Preclinical Training

Prior to their initial RB, trainees attended a didactic lecture and demonstration by the supervising faculty at each institution; basic hands-on RB training was provided on low-fidelity simulation manikins. Additionally, all participating fellows attended the IP Boot Camp organized by the American Association of Bronchology and Interventional Pulmonology at the beginning of their training, where they practiced RB on cadavers. All participating IP fellows were proficient in FB as it was a mandatory component of their prior pulmonary and critical care training. Participants were asked to complete a survey which included their demographics, prior FB and RB experience, and perceptions about RB (Table 1).

Rigid Bronchoscopy and RIGID-TASC Scoring

Supervising IP faculty scored every single RB performed by the participating trainee using the RIGID-TASC until the trainee achieved 89 points on 3 consecutive RBs at first attempt. The maximum score of 100 could be earned by optimally performing the various steps of RB, including pre-intubation assembly of RB, patient positioning, trauma prevention, and upper and lower airway navigation on a single attempt in a timely manner. At the end of each procedure, the learner received constructive, positive, and remedial feedback based on the RIGID-TASC checklist. These scores were plotted for each fellow to demonstrate the learning curves. All RBs were performed under general anesthesia using the rigid bronchoscopes (LYMOL Medical, Woburn, MA, USA, formerly Bryan Corp.) available at the respective institutions.

Statistical Methods

Data were presented by median and interquartile range (IQR) for continuous variables and percentage for categorical variables. The cumulative incidence curve was used to summarize the cumulative percentage of participants who achieved competency threshold over the number of RB procedures. The estimated number of RB procedures at which 25, 50, 75, and 100% of the participants reached competency threshold was calculated by one minus Kaplan-Meier estimate. We also used a learning curve estimating equation to simulate and fit participant learning patterns (details in the online suppl. material; for all online suppl. material, see

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Table 1. Participant demographics, FB experience, RB experience, and perceptions

Participant variable	Total (*N* = 12)
Age in years (median, IQR)	33.5 (32.0–34.0)
Gender	
Female	5 (42%)
Male	7 (58%)
Years graduated from medical school (median, IQR)	7 (6–9)
Practice setting prior to IP fellowship	
Pulmonary fellowship	11 (92%)
Academic appointment	1 (8%)
No. of FBs prior to IP fellowship (median, IQR)	200 (200–400)
Self-assessed FB level	
Beginner	2 (17%)
Experienced	9 (75%)
Expert	1 (8%)
No. of RBs prior to IP fellowship (median, IQR)	0 (0–0)
Self-assessed RB level	
Beginner	12 (100%)
Experienced	0
Expert	0
Believe that RB will be part of future practice	
Very likely	12 (100%)
Somewhat likely	0
Unlikely	0
Believe that RB should be reserved for those with IP training	
Yes	11 (92%)
No	1 (8%)
Believe that current IP training program offers adequate RB training	
Yes	12 (100%)
No	0

RB, rigid bronchoscopy; FB, flexible bronchoscopy; IP, interventional pulmonary; IQR, interquartile range.

www.karger.com/doi/10.1159/000514627). As the learning process progressed, the ability of each participant was expected to improve gradually up to an inflection point. After the inflection point, as the participant continued to acquire the skill, the performance score would remain relatively stable and a plateau was achieved. Participant RIGID-TASC scores over successive procedures were used to fit the model. We treated scores as continuous variable and number of procedures as the continuous time variable. The Gauss-Newton method was used to iteratively fit the estimating equation. Analysis was performed using SAS 9.4 (SAS Institute, Cary, NC) and R 3.4.1.

Results

Twelve participants were recruited upon starting their IP training between 2014 and 2017 (demographics shown in Table 1). After the initial pre-patient contact training (lecture and RB simulation on manikin and RB practice on cadaver at the IP Boot Camp), every clinical RB procedure was scored using the RIGID-TASC, starting from the first procedure until the threshold of 3 consecutive scores of 89 at first attempt was achieved (Fig. 1). The clinical indications included malignant central airway obstruction (38%), nonmalignant central airway obstruction (53%), and other miscellaneous indications (9%). A total of 178 RB procedures were performed by the participants and scored by the supervising IP faculty.

Participant learners achieved the threshold of 3 consecutive scores of 89 at first attempt in as few as 5 to as many as 24 RB procedures, with a median of 15 RBs. The performance of individual participants and summary regression curve is shown in Figure 1. There was a wide fluctuation of scores until a consistent plateau was achieved. In addition to the wide range of the scores obtained, participants were markedly different in their beginning score, slope of the learning curve, and inflection point (see online suppl. Fig. 1, 2 and see online suppl. Table 1). Trainees achieved the threshold of 3 consecutive scores of 89 at first attempt at different procedure volumes with 25% compe-

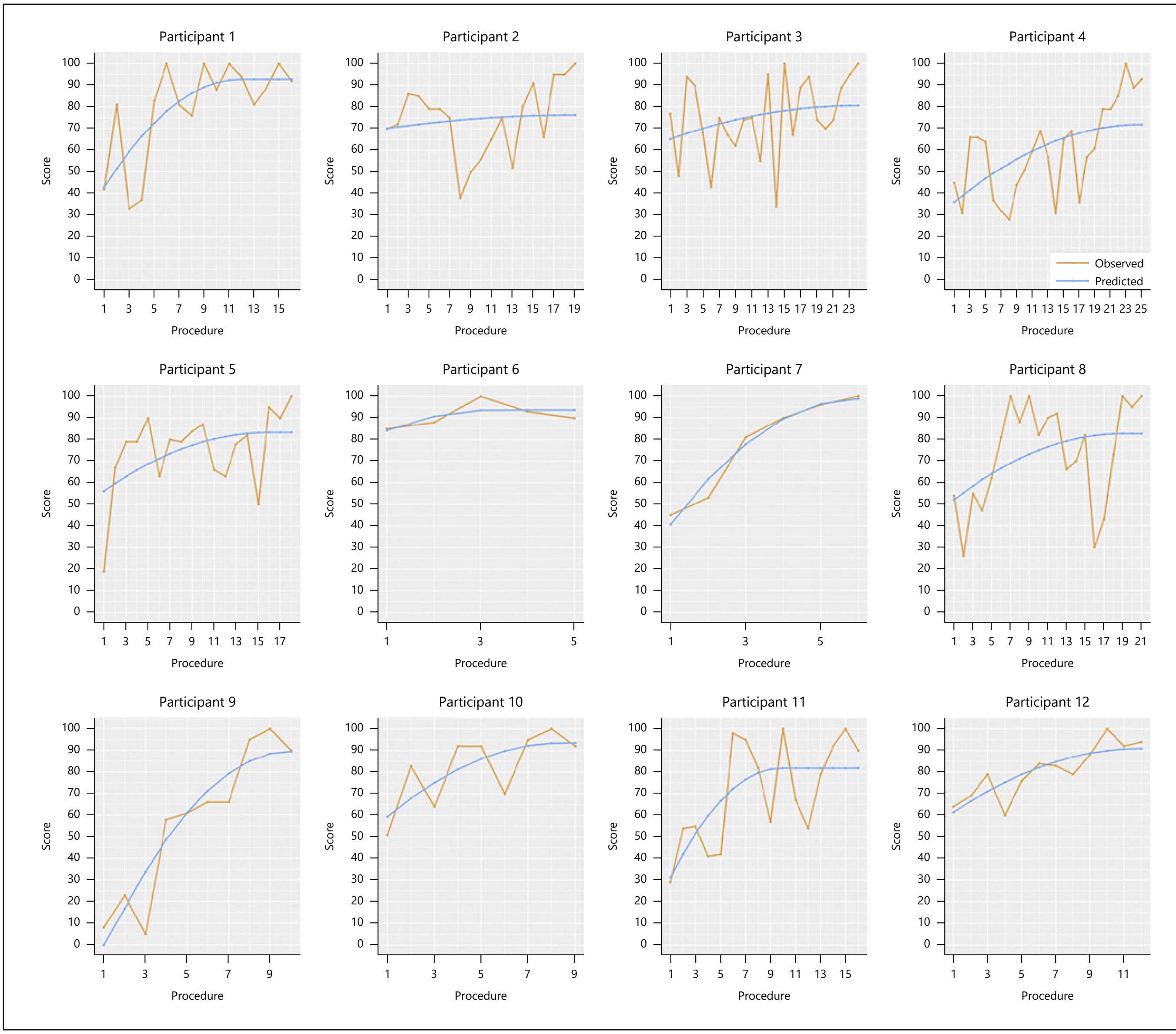

Fig. 1. Learning curve of the individual participants. The learning curve based on raw data and the summary regression curve for each participant is shown.

tent at 9 RBs (95% CI, 5–15); 50% at 15 procedures (95% CI, 6–21); 75% at 20 RB (95% CI, 15–24); and 100% trainees at 24 RB, as shown on the cumulative incidence curve in online suppl. Fig. 3.

We also assessed the learners' performance of different steps of RB using subtasks of the RIGID-TASC checklist, in order to determine which subtasks were most difficult to master as shown in Table 2 and Figure 2. The competency threshold for the subtask was defined as the ability to perform that subtask without any assistance from the supervisor in 3 consecutive RB procedures. Two subtasks were the most difficult to master as they needed the most number of attempts to achieve the threshold of 3 consecutive successful attempts: the ability to intubate the patient on the first attempt (median 10, IQR 8–16) and ability to complete intubation from introduction of bronchoscope into mouth to trachea within 1 min (median 9.5, IQR 7–18.2). Other subtasks that required more attempts to master included the ability to obtain full view of larynx (median 6.5, IQR 4–8), avoiding excessive contact or in-

Table 2. Attempts to achieve competency threshold in subtasks of RIGID-TASC

RIGID-TASC subtask	Attempts to achieve competency threshold in subtask,* median (IQR)
1. Correct assembly of bronchoscope	4 (3–7)
2. Correct positioning of the head of the patient	3 (3–4.5)
3. Protection of lips and teeth	4 (3–5.2)
4. Holds the bronchoscope with right hand	3 (3–3)
5. Holds the bronchoscope with bevel up	3 (3–3)
6. Stabilization of telescope in the rigid bronchoscope	4.5 (3–8.5)
7. Correct positioning of telescope so that whole distal rim of rigid bronchoscope is visible	3 (3–4.5)
8. Correct positioning of suction catheter in the bronchoscope	3 (3–4.2)
9. Introduction of rigid bronchoscope into the airway at appropriate angle	3.5 (3–4)
10. Follows tongue/uvula to epiglottis	4.5 (3.7–5.2)
11. Elevates epiglottis	3.5 (3–6.2)
12. Able to obtain full view of vocal cords	6.5 (4–8)
13. Avoids excess contact/injury to arytenoids	6.5 (5–9.2)
14. Able to insert bronchoscope through vocal cords with 90° rotation so that bevel is parallel to vocal cords	7 (3–9)
15. Advances scope further with bevel down in trachea	3.5 (3–5.2)
16. Keeps the rigid scope centered in the airway to avoid trauma	5.5 (4–9.5)
17. Able to insert bronchoscope into trachea at the first attempt	10 (8–16)
18. Positions upper teeth guard correctly	3 (3–5.2)
19. Turns head to the opposite side to advance scope into right mainstem bronchus	3 (3–5)
20. Able to manipulate scope into distal bronchus intermedius	3 (3–4.5)
21. Turns the head to the opposite side to advance scope into left mainstem bronchus	3 (3–5.2)
22. Able to manipulate scope into distal left mainstem bronchus	3 (3–5)
23. Able to complete the procedure from introduction of bronchoscope into mouth to trachea in <60 s	9.5 (7–18.2)

RB, rigid bronchoscopy; RIGID-TASC, Rigid Bronchoscopy Tool for Assessment of Skills and Competence; IQR, interquartile range.
* Competency threshold was defined as the ability to complete the subtask in 3 consecutive RB procedures.

jury to arytenoids (median 6.5, IQR 5–9.2), the ability to rotate the bronchoscope 90° with the bevel parallel to vocal cords prior to passing through (median 7, IQR 3–9), and keeping the scope centered in the airway to avoid unnecessary tissue trauma (median 5.5, IQR 4–9.5).

The perception of participants about RB has been included in Table 1. They were of the opinion that their current IP fellowship offered adequate opportunity to gain competence in RB, and most of them believed that RB is an advanced skill which should be learned in a dedicated fellowship program. They also felt that RB would be incorporated into their clinical practice after the training. There were a few complications associated with RB, including 1 loose tooth, 2 upper airway mucosal injuries, 2 lower airway mucosal injuries, and 2 incidents of hypoxemia with oxygen saturation of ≤88%.

Discussion

This is the first study to objectively measure, plot, and compare the skill acquisition of RB learners in a clinical setting. We used a previously published tool, RIGID-TASC [12], to objectively assess serial RBs performed by IP trainees until a designated competency threshold was reached; this was defined as independently performing RB intubation and navigation in 3 consecutive patients at first attempt while obtaining a predefined score. We demonstrated that RIGID-TASC could accurately measure the minimal fluctuations in operator performance from 1 procedure to the next, and it was effectively used to measure and plot RB skill acquisition curves in IP trainees to the threshold where a consistent level of competency was achieved. More significantly, we demonstrated that there was a difference in the rate that skills were acquired as the learners had learning curves that varied widely.

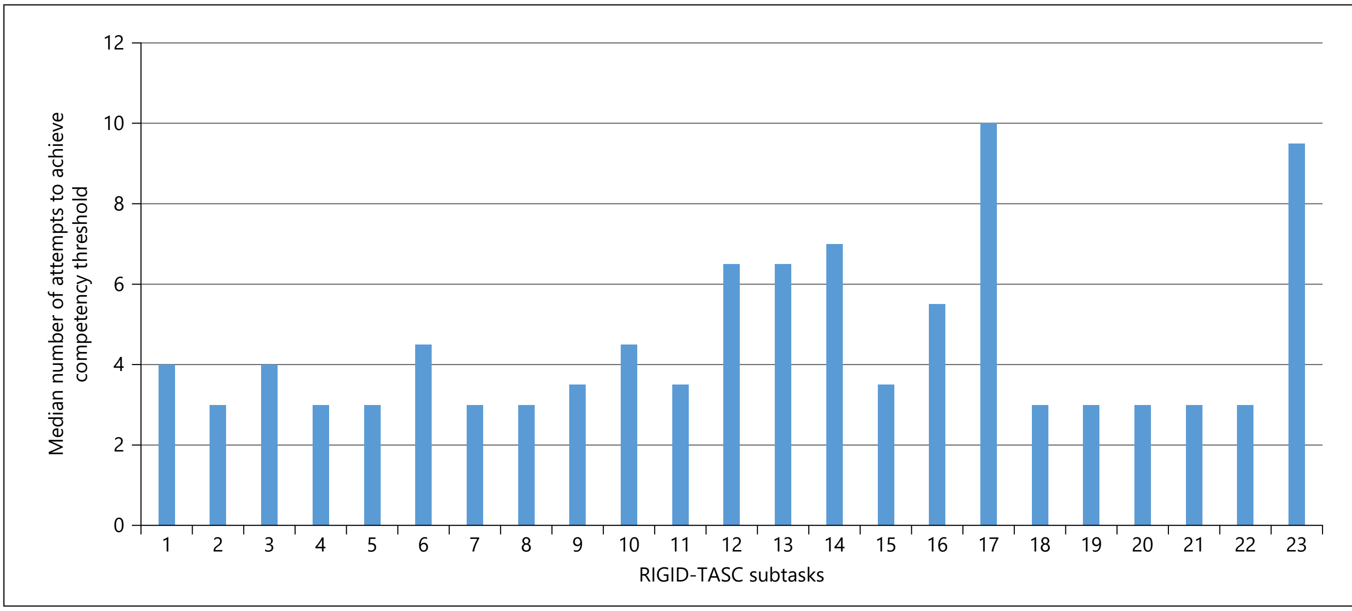

Fig. 2. Performance of participants on the subtasks of RIGID-TASC. Subtasks (1) assembly of bronchoscope; (2) patient's head positioning; (3) lips and teeth protection; (4) bronchoscope handling; (5) bronchoscope bevel up; (6) telescope stabilization; (7) telescope positioning in bronchoscope; (8) suction catheter positioning; (9) insertion angle of bronchoscope; (10) follows tongue/uvula; (11) elevates epiglottis; (12) obtains full vocal cords view; (13) avoids injury to arytenoids; (14) rotates bronchoscope 90° through vocal cords; (15) advances scope with bevel down in trachea; (16) keeps scope centered; (17) intubation attempts; (18) teeth guard use; (19) turns head to left to advance scope into right mainstem bronchus; (20) able to advance scope into bronchus intermedius; (21) turns the head to the right to advance scope into left mainstem bronchus; (22) able to insert scope into distal left mainstem bronchus; (23) able to introduce scope from mouth to trachea in <60 s. RIGID-TASC, Rigid Bronchoscopy Tool for Assessment of Skills and Competence.

The trainees obtained a wide range of scores on their initial RB, while their gradual upward trends also followed different curves in terms of shape, slope, acceleration (negative vs. positive), degree of up-and-down fluctuation, and the inflection point leading to the plateau. We used a curve-fitting technique that was modified to depict and compare the different important parameters such as starting point, slope, inflection point, and plateau. Similar statistical methodology has been used in surgical competency assessment literature [13], yet it has not been utilized to assess bronchoscopy learning patterns.

Prior studies have shown that learners acquire procedural skills and achieve competency at differing rates. In a study looking at the experience of thirteen pulmonary fellows learning endobronchial ultrasound, the trainees needed a varying number of procedures (5–13), in order to perform the procedure independently [11]. Our study demonstrated that the learning curve for RB is more variable, with the number of procedures required to achieve initial competency ranging from 5 to 24 procedures. This further underscores the notion that one-size-fits-all number criteria to achieve competency ignore this inter-learner variability.

Professional societies are mandated to develop minimum standards to certify the competency of graduating trainees. To this end, ATS and ACCP have published guidelines, based on the expert opinion, suggesting twenty RBs as threshold to achieve initial competency [7–9]. These organizations, and later a multi-society IP fellowship accreditation committee, have acknowledged the limitation of procedure-volume quota as a competency metric [3]. An ACCP expert panel has recommended that organizations certifying pulmonary trainees should transition from volume-based certification to objective competency assessments based on skill and knowledge acquisition [6]. We use RIGID-TASC, a previously developed assessment tool, to address this gap for basic RB training. We demonstrate that it can effectively measure and plot the skill acquisition of trainees from the point of skill transfer in a simulation laboratory to achievement of clinical competency threshold.

In an era of simulation-based education, it is now established that patients must not bear the burdens of procedure-related training. The higher the risk of potential harm a procedure may pose to our patients, the more imperative it becomes that the basic skills are learned on a simulation model [10]. The next important step is the seamless transfer of the acquired skills to the clinical setting. The effectiveness of this skill transfer has been demonstrated in many procedural fields [14–16]. Of the different major procedures taught during IP fellowship, RB is one of the most invasive procedures that can lead to significant morbidities if performed poorly. The ability to objectively demonstrate the effective transfer of RB skills to the patient's bedside, while measuring and plotting the learning curve to a competency threshold is of utmost importance; we demonstrated this process in the current study. In addition, each learner's RIGID-TASC scores, especially the sub-scores for each of the constituent components, were used by supervising faculty to deliver personalized, objective feedback, making this a process of *iterative deliberate practice.* Repeated use of an assessment tool to guide learning is what has been coined as *dynamic testing or assessment* [17, 18].

A major reason we broke down RB into its stepwise components in RIGID-TASC was to guide the process of iterative feedback between consecutive procedures. There are 23 steps or subtasks necessary to perform RB intubation and airway navigation based on RIGID-TASC. We found that trainees had the most difficulty with and needed more procedures to learn composite tasks: intubation at first attempt and completion of intubation within 60 s. Other areas which required more procedures were centering the RB during airway navigation and avoiding unnecessary trauma to the arytenoids, vocal cords, and lower airway. Salud and colleagues [5] had also observed that during RB on a pressure-sensor mounted manikin, a key feature that differentiates novice from expert bronchoscopists is a higher number of unnecessary tissue contact and increased pressure. Acquiring this precise, objective data for each individual learner allows for extra remedial attention and deliberate practice, focused on each learner's weaknesses.

Extensive research exists on the rates and patterns with which learners acquire procedural skills. A significant portion of this literature focuses on the different factors that impact the characteristics of the learning curve [19]. Some of the more crucial factors include the nature of the task, in terms of complexity and ratio of pure motor versus cognitive and other skills; task difficulty as it impacts positive versus negative acceleration of the curve, and how intense difficulty makes the task less sensitive to deliberate practice; degree of prior learning, either of the entire task or its components; the threshold for training termination, when "mastery level" has been achieved; the temporal distribution of practice and the role of interference and forgetting; differences among individuals and training methods; the effects of interest and motivation; and the correlations between the pattern and slope of learning curve with retention. We devised a novel curve-fitting model and successfully pilot-tested it to create a template for RB. This model can also be used to systematically determine learning curves for other procedures. We can then assess how changing combinations of the factors listed above may impact the slope, inflection, and plateau of the learning curve and ultimately the training outcome. This information can be used to improve coaching methodology and parameters, training more effective and masterful operators while improving return on investment in resources and time.

The strengths of our study include the prospective utilization of a previously developed assessment tool to objectively measure the acquisition of clinical RB skills by IP trainees and the use of an innovative curve-fitting model to plot learning curves for comparison. The weaknesses of the study include small sample size of participants and that knowledge, cognitive, and decision-making skills were not assessed. The score of 89 was chosen as the minimum criterion for basic competency because it was the lowest score achieved by one of the experts in the original validation study [12]. We also did not include assessment of adjunct therapeutic procedures, performed either by flexible bronchoscope introduced through rigid bronchoscope – such as self-expandable stent placement and use of ablative therapies – or RB coring and silicone stent placement. There are different competency metrics for these endobronchial procedures, as underscored by an ACCP statement [9]. As training in the therapeutic procedures logically follows achievement of competence in RB intubation and navigation, these adjunct skills could be evaluated in future studies.

Conclusion

This study demonstrated that RIGID-TASC can be effectively used to assess and plot acquisition of RB skills, from the point of skill transfer in a simulation laboratory to the clinical setting. In addition, novice learners acquire RB skills with widely different learning curves and the currently established guidelines and practices to evaluate competency need to be updated.

Acknowledgements

We acknowledge the resolve and perseverance of all the trainees and their mentors.

Statement of Ethics

Research complied with the guidelines for human studies and was conducted ethically in accordance with the World Medical Association Declaration of Helsinki. All the trainee participants provided written informed consent for participation. The study was approved by the institutional review board of all the participating institutions: Duke University (Pro00055274), Virginia Commonwealth University (HM20002272), Johns Hopkins University (00139179), and Emory University (00075805).

Conflict of Interest Statement

No author has any conflict of interest pertaining to this study.

Funding Sources

There was no funding source for this study.

Author Contributions

K.M. and M.D. wrote the manuscript which was reviewed, edited, and approved by all authors. K.M., M.M.W., C.R.L., and M.D. designed the study; K.M., M.M.W., W.S., A.C.C., L.B.Y., H.L., S.S., D.M.B., K.V.N., and S.L.S. collected and interpreted the data; J.G., K.M., and M.D. analyzed the data.

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