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REPORTS OF ORIGINAL INVESTIGATIONS

Learning curves of novice anesthesiology residents performing simulated fibreoptic upper airway endoscopy

Courbes d'apprentissage des nouveaux résidents en anesthésiologie réalisant une endoscopie des voies aériennes supérieures par fibre optique en simulation

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Abstract

Background *In various medical and surgical specialties, it is essential to acquire fibreoptic upper airway endoscopy skills for successful endotracheal intubation, especially when faced with a difficult airway. The aim of our study was to evaluate the learning curves of residents performing fibreoptic upper airway endoscopy in the simulation environment.*

Methods *Following a standardized video and practice session, 16 residents newly enrolled in the anesthesiology program performed nasal fibreoptic endoscopy of the upper airway (endpoint being the carina) on a high fidelity simulator. Weekly 20-min sessions continued for a period of one month. Each attempt was designated as either a "success" or a "failure" based on the study participant's ability or inability to visualize the carina in ≤60 sec and with ≤five collisions with the simulated mucosal wall. Proficiency was attained when the downward graphical trend of the cumulative sum (CUSUM) analysis crossed two adjacent boundary lines, i.e., an acceptable failure rate was reached.*

Results *The residents' mean number of attempts at fibreoptic airway endoscopy was 47 (9) with a range of 32–64. Time to visualization of the carina was 51 (36) sec. Three classical patterns of CUSUM trends were observed: proficient (n = 7); not proficient with a downward (improvement) trend (n = 3); and not proficient with an upward (worsening) trend (n = 6). The number of attempts at which proficiency was achieved varied from 27 to 58.*

Conclusion *There is a large variation in the learning curves of residents performing fibreoptic upper airway endoscopy. The training for fibreoptic airway endoscopy should be tailored to the needs of each individual.*

Résumé

Contexte *Dans différentes spécialités médicales et chirurgicales, l'acquisition de compétences en matière d'endoscopie des voies aériennes supérieures par fibre optique est essentielle pour réussir une intubation endotrachéale, particulièrement lorsqu'on est confronté à des voies aériennes difficiles. L'objectif de notre étude était d'évaluer les courbes d'apprentissage des résidents réalisant une endoscopie des voies aériennes supérieures par fibre optique dans un contexte de simulation.*

Méthode *Après une séance standardisée de vidéo et de pratique, 16 résidents nouvellement inscrits au programme d'anesthésiologie ont réalisé une endoscopie nasale par fibre optique des voies aériennes supérieures (jusqu'à la carène) sur un simulateur haute fidélité. Des séances hebdomadaires de 20 min se sont poursuivies pendant un mois. Chaque tentative a été considérée comme étant soit une « réussite » ou un « échec » selon la capacité ou l'incapacité du participant à l'étude à visualiser la carène en ≤60 sec et avec ≤cinq collisions contre la paroi*

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muqueuse simulée. La compétence était atteinte lorsque la tendance graphique vers le bas de l'analyse de la somme cumulée (CUSUM) croisait deux lignes de délimitation adjacentes, c.-à-d. qu'un taux d'échec acceptable était atteint.

Résultats *Le nombre moyen de tentatives des résidents pour l'endoscopie des voies aériennes par fibre optique était de 47 (9), avec des résultats allant de 32 à 64. Le temps jusqu'à visualisation de la carène était de 51 (36) sec. Trois schémas classiques de tendances de CUSUM ont été observés : compétent (n = 7); non compétent avec une tendance à la baisse (amélioration) (n = 3); et non compétent avec une tendance à la hausse (aggravation) (n = 6). Le nombre de tentatives pour atteindre la compétence variait de 27 à 58.*

Conclusion *Il existe une importante variation dans les courbes d'apprentissage des résidents réalisant une endoscopie des voies aériennes supérieures par fibre optique. La formation pour l'endoscopie des voies aériennes par fibre optique devrait être personnalisée selon les besoins de chacun.*

Acquisition of knowledge and skills pertinent to the use of fibreoptic endoscopy is an important part of training in various medical and surgical specialties such as anesthesiology, emergency medicine, otolaryngology, and pulmonary medicine. In their practice guidelines for the management of the difficult airway, the American Society of Anesthesiologists has also mentioned the use of fibreoptic intubation as one of the available options.[1] The scope of technical skills to learn and add to the armamentarium of professionally trained anesthesiologists has increased. However, hands-on training on live subjects can potentially expose patients to increased risks of trauma and desaturation.[2,3] In a simulated environment, the trainee has the advantage of concentrating on developing skills with repetitive practice[5] without the risk to human or animal life. Hence, use of simulation has become tremendously popular.[5,6] However, only a few studies[7-9] indicate the minimum number of procedures required to achieve a certain level of competence or proficiency in performing a given procedure. It is also a challenge to assess the level of proficiency a resident achieves in the simulation environment.[10] Although there are several subjective performance rating scales described in the literature, the use of an objective statistical tool, i.e., the cumulative sum (CUSUM) analysis, has been advocated for tracking the performance of a resident over a period of time.[10-12] This statistical tool may therefore be used to analyze the performance of residents learning technical procedures such as fibreoptic endoscopy skills.

We planned to evaluate the number of attempts that novice anesthesiology residents would require to achieve a competency level (visualization of the carina in ≤60 sec and with ≤five collisions) while striving to perform fibreoptic airway endoscopy with proficiency. The primary objective of our study was to use CUSUM analysis to evaluate the learning curves of the residents at performing fibreoptic upper airway endoscopy. The secondary aim of our study was to determine the number of attempts a novice resident would require to achieve the proficiency level (visualization of the carina in ≤60 sec and with ≤five collisions) in the use of fibreoptic endoscopy over a period of two months.

Methods

Following Institutional Review Board approval and informed consent from the participants, 16 anesthesia residents at Penn State Hershey Medical Center were enrolled in the study from July 1, 2009 to August 31, 2009. The study was performed in the simulation centre at the Penn State Milton Hershey Medical Center. Study subjects were excluded if they had independently performed a fibreoptic endoscopy in the simulation centre or in the clinical setting. The simulation scenario used throughout the study period was that of an adult 42-yr-old female with a history of hemoptysis who presented for awake fibreoptic bronchoscopy with topicalization with lidocaine. The residents received a 15-min practice session with the instructor prior to commencing the study. An instructor with more than ten years of experience in fibreoptic endoscopy was present throughout the study period and conducted all of the training sessions.

Two faculty anesthesiologists (each with more than ten years of experience in anesthesia) considered departmental experts in fibreoptic airway endoscopy performed 20 attempts each at fibreoptic airway endoscopy on the same high-fidelity simulation mannequin. The two experts each achieved a 95% success rate; time to visualization of carina was 33 (12) sec and 44 (15) sec, respectively, with the number of collisions ranging from 0 to 4. Based on these findings and after general consensus, the criteria for a successful attempt were set as the ability to visualize the carina in ≤60 sec and with ≤five collisions with the simulated mucosa wall.

The simulator model was the Accutouch® Endoscopy Simulator (Immersion Medical now acquired by CAE Healthcare, San Jose, CA, USA). This model is essentially a bronchoscopy simulator without the capacity for use as an intubating mannequin. The endoscope is 539 mm in length with an outer diameter of 5.26 mm. It has a modified end piece that allows the endoscope to be "captured" by the mannequin upon insertion. The simulator itself is an interactive virtual reality endoscopic simulation platform with a haptic interface that provides force feedback simulating the actual procedure. The features include: the feel of a realistic tissue, movement of tissue when touched with the fibreoptic scope, involuntary muscle contractions, bleeding, and resistance while negotiating the endoscope during the simulated procedure.

To begin with, the study subjects were shown the standardized video that is incorporated in the simulation system. This included six introductory video clips: demonstrating use of the fibreoptic endoscope, inserting the endoscope, topicalization of the airway, transnasal insertion of the bronchoscope, topicalization of the vocal cords, and traversing the vocal cords. Next, the study subjects were given a 15-min practice session with the use of the fibreoptic endoscope. Once each week for a period of one month, the study participants performed the fibreoptic airway endoscopy on the simulator repeatedly for 20 min. Eight of the 16 residents participated in the study during July 2009 and the remaining eight residents participated during August 2009. The same instructor provided a brief feedback after each attempt. The fibreoptic endoscope was used nasally in all cases, and the residents performed fibreoptic endoscopy on the simulator with an unlimited number of attempts during each session. The CUSUM analysis was performed after the study process was completed, with the primary endpoint being the dichotomous variables, "success" or "failure", as defined below. The data regarding attempt number, number of collisions, and "red-out" time were recorded by the computer within the simulator model. The instructor obtained the values of these parameters from the computer record after each attempt. The parameters included:

1. Total procedure time = from the time the resident picked up the scope until the carina was visualized;
2. Number of collisions (n) = the number of times that the tip of the bronchoscope collided with the surface of the pharynx, larynx, and trachea;
3. Red-out time (R) = time the resident spent viewing the mucosal wall without any identifiable structures;
4. Success = resident able to visualize the carina in $\leq$60 sec and with $\leq$five collisions with the simulated mucosa wall; and
5. Failure = resident takes >60 sec to visualize the carina or has >five collisions with the simulated mucosa wall.

Statistical analysis

The primary outcome variable was the number of attempts required to achieve a "success". The secondary outcome variables were the (1) time taken to visualize the carina, (2) the number of collisions, and (3) the "red-out" time as defined above. Data for the number of attempts, time to visualization, number of collisions, and the "red-out" time were described using mean and standard deviation for normally distributed data and median and range for data that was not normally distributed. The data were analyzed using Microsoft Excel 2007.

The acceptable and unacceptable failure rates were determined by CUSUM analysis.[11-13] An acceptable failure rate was set at 10% ($p_0 = 0.1$), and an unacceptable failure rate was set at 20% ($p_1 = 0.2$). Also, we set the type I error rate $\alpha = 0.1$ and type II error rate $\beta = 0.1$. The values of p_0, p_1, α, and β determined the amount (s) by which the sum decreases if there is a "success" (see Appendix for details). In the present study, $s = 0.145$. If there was a "failure", the sum increased by $1 - s$ or 0.855. The CUSUM chart is completed by upper (h_1^-) and lower (h_0^-) boundary lines which are horizontal and separated by 2.71 units (Appendix). The distance between two adjacent boundary lines depends on the probability of a type I error (risk of declaring competence when it is not achieved) and a type II error (risk of not declaring competence when it has been attained). A line to describe the progress of each resident was drawn on the CUSUM graph. The resident was deemed "proficient" if his/her line crossed two adjacent or consecutive boundary lines from above, i.e., an acceptable failure rate was reached. The resident was deemed "not proficient" and in need of further training if the graphical trend was upwards or if it moved downwards at each attempt but failed to cross two consecutive boundary lines from above.

Results

There were 16 residents (11 male and five female) who participated in the study (Table). Ten residents were in their first postgraduate year of training and six residents

Table Demographic and general data for all residents

Parameter	Values
Total residents	16
Sex ratio, M:F	11:5
Age (yr) range	25–30
Number of attempts, mean (SD) range	47 (9) 32–64
Total time (sec) mean (SD), range	51 (36) 12–539
Number of collisions, median (IQR)	1 (0–2)
Red-out time (sec) median (IQR)	0.01 (0–0.03)

SD = standard deviation; M = males; F = females; IQR = interquartile range

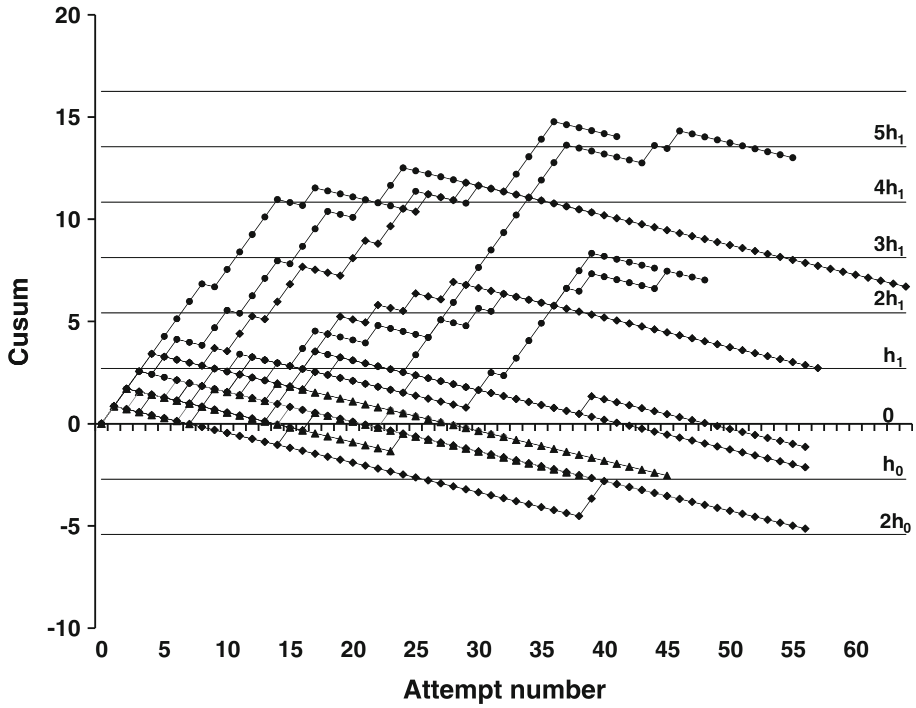

Fig. 1 Overall performance trends for each resident ($n = 16$). The cumulative sum (CUSUM) is plotted against attempt number. The upper (h_1) and lower (h_0) boundary limits are constructed depending on type I and type II error rates which are both set at 0.1. The graph points for residents who are "proficient" are indicated as solid diamonds ($n = 7$); those for residents who are "not proficient" but have a downward (improving) trend are shown as solid triangles ($n = 3$), and those for residents who are "not proficient" with an upward (worsening) trend are shown as solid circles ($n = 6$).

were in their second postgraduate year of training; however, the six residents spent their first year in a non-anesthesia specialty. Three of the 16 residents had five or fewer visual exposures to fibreoptic endoscopy, and the rest of the 13 residents had no prior exposure to fibreoptic endoscopy.

The overall trends in resident performances are shown as a CUSUM graph in Fig. 1. Seven of the 16 residents achieved proficiency. The number of attempts at which proficiency was achieved varied from 27 to 58 (median 42, interquartile range 40–53). An example of this trend is shown in Fig. 2. Three of the remaining nine residents who were deemed "not proficient" showed a downward trend but stopped short at the second boundary line, suggesting that proficiency would be reached if further attempts were made (Fig. 3). The other six residents demonstrated an upward trend and crossed two boundary lines from below (Fig. 4). The graph of an "expert" faculty is shown in Fig. 5.

Discussion

This study shows that there is a wide variation in the learning curves of residents and the number of attempts to achieve proficiency in performing upper airway endoscopy. Each individual's learning curve may depend on multiple factors, such as aptitude, inherent skills, enthusiasm on the part of the learner, and the experience and enthusiasm generated by the teacher, although these factors were not a focus of our study.

There are two specific challenges that an instructor and trainee may encounter during the process of imparting and acquiring a practical skill. The first challenge points to the type of model used for learning, e.g., live subjects in a clinical situation, cadavers, animal models, or simulator models. The second challenge points to the ability to assess whether the training was successful and whether the trainee reached an acceptable level of proficiency.[10] In anesthesia training, there are few reports of standardized testing or assessing for proficiency in psychomotor skills,[14] such as peripheral or central venous cannulation, tracheal intubation, central or peripheral neural blockade, and fibreoptic endoscopy. Performance in practical skills may be assessed by various means, including but not limited to logbooks, use of global rating scales, or the CUSUM analysis.[9,14] Assessing and teaching performance skills can be carried out in the clinical setting,[14] on cadavers, or in the simulation environment.[15,16] There are also reports of teaching fibreoptic endoscopy skills in the simulation environment and its successful transfer to the clinical setting.[17–19] Reports in the available literature regarding the minimum number of cases required to complete a training module in gastrointestinal endoscopy,[8,9] pulmonary bronchoscopy,[7] and anesthesia-related procedures[10,14] are not based on objective criteria. Statistical process control techniques,[20-23] such as CUSUM analysis, can be used to examine objectively the sequence of successes and failures in performing a task repetitively. The CUSUM analysis has been used previously in anesthesiology and is employed in the present study. To determine whether future performance is likely to be adequate, CUSUM

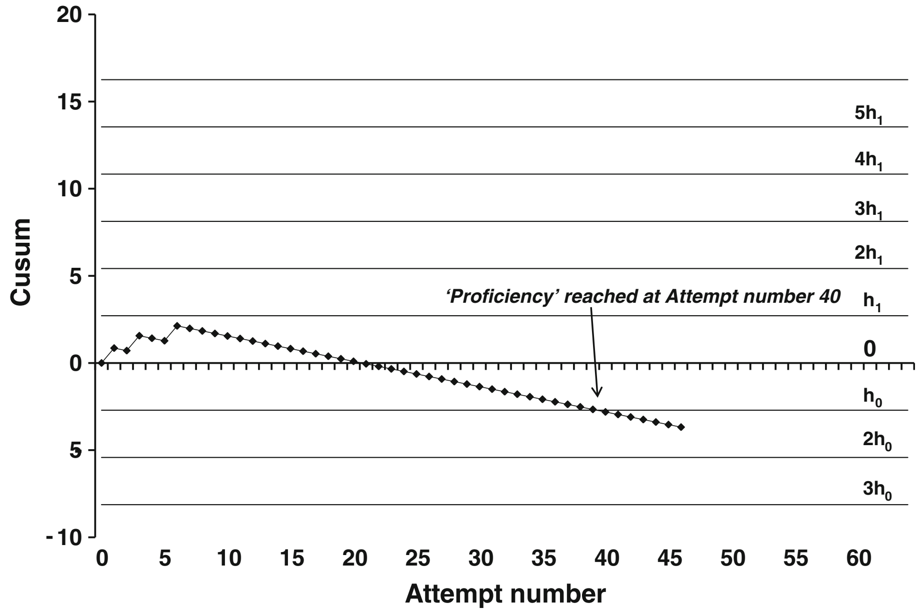

Fig. 2 An example of an individual resident's performance trends wherein a resident achieves "proficient" status when crossing two consecutive boundary lines in a downward trend; the attempt number at which "proficient" status is achieved is 40.

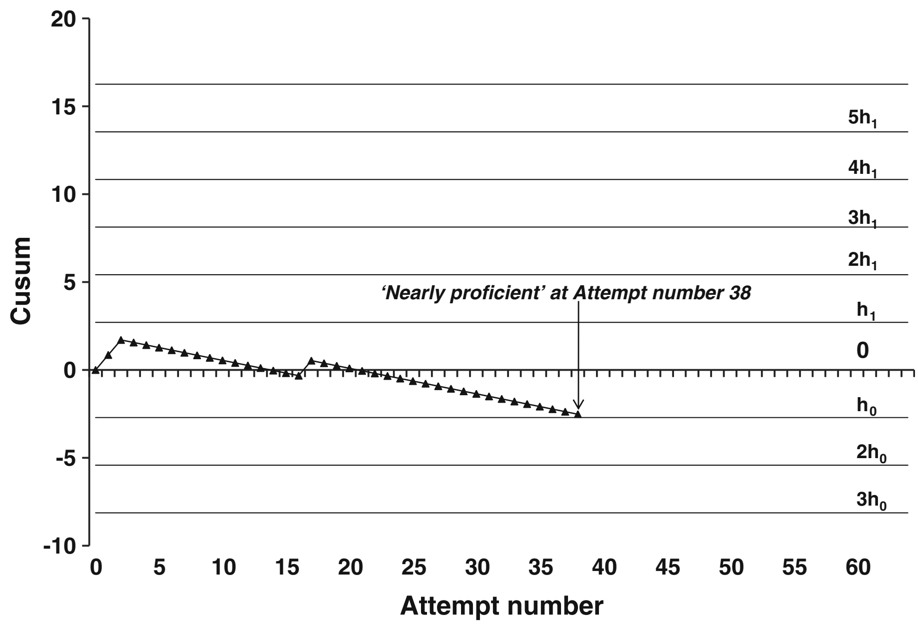

Fig. 3 An example of an individual resident's performance trends wherein a resident who is deemed "not proficient" with a downward (improving) trend; the attempt number at which "near proficient" status is achieved is 38.

analysis depends on predetermined acceptable and unacceptable failure rates for the procedure in question. The likelihood of a false positive or a false negative prediction of future success is given by type I and type II errors, respectively, and these error rates must be explicitly stated. In this study, both type I and type II values were set at 0.1. Since CUSUM is based on self-reporting the performance, it has potential for inaccuracies. However, the results of the CUSUM in our study were compiled by the computer software in the simulator model, and the observations were noted by the instructor at the end of each attempt, thus minimizing the chance of inaccuracy. Other limitations of CUSUM analysis include a wide variation in definitions, setting a predetermined endpoint (as in our study), and deterioration of the individual's curves if more challenging situations are encountered for the skill that is being evaluated.[10] Finally, previous studies have shown that a wide variation in the number of attempts may be required to achieve proficiency. Based on our study, where $s = 0.145$ and $h_0 = -2.71$, if all attempts by an expert were successful, proficiency would be demonstrated on the CUSUM only after 18 successful attempts. However, the two expert faculty members in our study had an initial failed attempt followed by all successful attempts. Since they had a total of only 20 attempts (Fig. 5), proficiency could not be demonstrated by CUSUM analysis unless they had 23 successful attempts (i.e., proficiency after

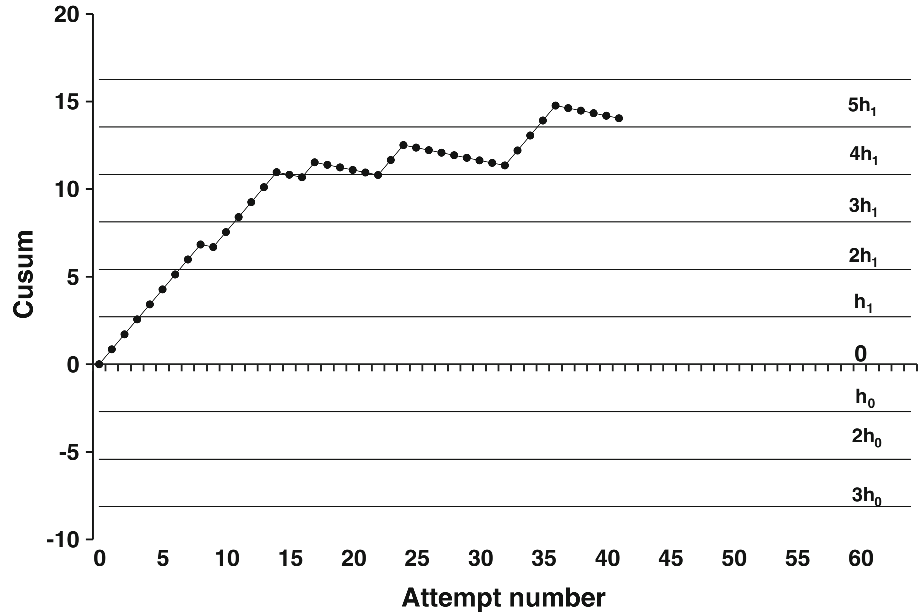

Fig. 4 An example of an individual resident's performance trends wherein a resident who achieves "not proficient"' status with an upward (worsening) trend in the CUSUM graph.

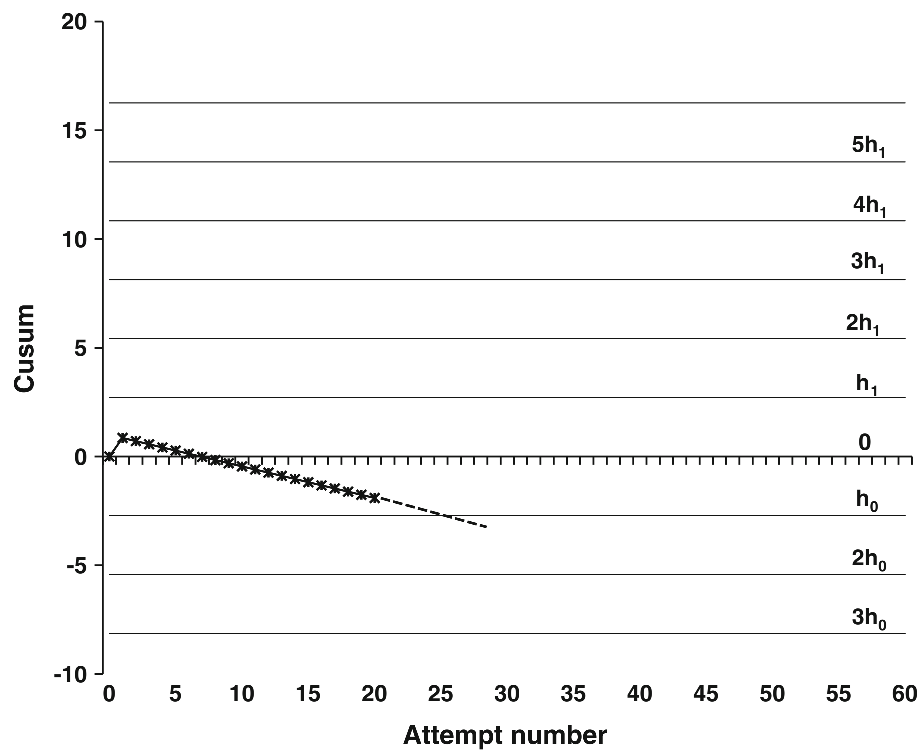

Fig. 5 An example of the performance trend of an expert faculty who had a maximum of 20 attempts; the graph line is extrapolated for further consecutive successful attempts, suggesting that proficiency would be achieved on the 24th attempt.

24 attempts, the first failed attempt and 23 successful attempts). This is an interesting observation suggesting that a large number of attempts may be required to demonstrate proficiency. Rather than considering the CUSUM method alone, other methods of evaluation, such as global rating scales and checklists, must be considered for evaluation of competency in a procedural skill.[10]

In our study, we used a very stringent definition for a successful attempt. We chose to define a "success" based on a time limit as well as a number of collisions. Based on preliminary data from the performance of expert faculty with a 95% success rate under the same simulation environment, we chose the time to visualization of the carina as ≤60 sec. In a study by Goldmann and Steinfeldt[16] involving novices in training, they reported a 114 sec mean time to intubation on the virtual reality simulator and 86 sec on cadavers. On the other hand, the authors[16] reported the experts' mean times to intubation as 23 sec on cadavers and 79 sec on the virtual reality simulator. The time limit in our study (60 sec) is close to or within this range. In our study group, the overall mean time to a successful endoscopy (endpoint = visualization of the carina) was 50 sec. The time to complete a procedure successfully is significant because it has implications on real-life situations.

Our rationale for limiting the number of collisions was based on the standard set by our expert faculty who had a collision range of 0–4 during the course of 20 attempts at airway endoscopy in the same setting. The number of collisions as a measure of efficiency in fibreoptic endoscopy has been used in a previous study[5] as it is a frequent clinical observation that direct collisions with the peripheral wall during clinical practice lead to trauma and bleeding and may worsen a subsequent attempt at fibreoptic laryngoscopy. Our study on the simulation mannequin may not have been able to simulate the occurrence of secretions, movement, or bleeding as well as in a real-life situation.

We found that the residents in our study who achieved the proficiency level required a median of 42 attempts. This result differs from the study by Johnson and Roberts[24] who demonstrated that the novice resident may reach expertise in fibreoptic intubation in the clinical setting by the tenth attempt. Although the residents found to be "not proficient" made a slightly lower number of attempts compared with the rest of the residents, the difference was not significant. Interestingly, we noted two trends in our study in the "not proficient" group. First, there was a small subset in the "not proficient" group with a trend towards achieving proficiency, suggesting that these residents are trainable to achieve a proficiency level with more practice. Second, the subset of residents whose CUSUM trends went upwards needed to undergo more rigorous training in the form of one-on-one teaching and training at workshops in order to achieve proficiency. Further evaluation of this group over time may reveal their ability to achieve the required level of proficiency in terms of the time line and the required number of practice attempts.

Study limitations

There are several limitations to our study. First, our study subjects had a variable number of attempts at fibreoptic endoscopy. Perhaps comparisons among residents may have been more appropriate if they all had an equal number of attempts. However, the focus of our study was to establish individual resident's learning curves and their trends as analyzed by CUSUM analysis. Second, we used visualization of the carina as the endpoint for each attempt, as the technical limitations of the simulator precluded the use of endotracheal intubation (following the airway endoscopy) as a part of the study. Our focus was on dexterity in manipulating the fibreoptic endoscope. Perhaps clinical relevance to fibreoptic laryngoscopy and endotracheal intubation would have been more appropriate if it were technically possible with the simulator used in the study. Finally, our study was performed in the simulation environment, which may not fully replace the experience and the stress of a real-life situation.

In conclusion, we have demonstrated use of CUSUM as a tool for assessment of performance. This tool can be used by individual program directors to track the performance of each resident over a period of time and to identify those residents who may require extra training to reach an acceptable level of proficiency. However, CUSUM analysis may have some limitations that need to be addressed when used as an assessment tool for achievement of proficiency in procedural skills. Our results also demonstrate that there is a wide variation in the learning curves of individual residents. Transferring this information to the operating room situation would be interesting and warrants further study.

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Conflicts of interest None declared.

Appendix

Calculation of cumulative sum (CUSUM) boundary lines[14]

We used the following parameters to construct a CUSUM chart with boundary lines:

p_o = acceptable failure rate under the null hypothesis = 0.1

p_1 = unacceptable failure rate under the alternative hypothesis = 0.2

α = type I (false alarm) error rate, the risk of accepting a bad batch of observations = 0.1

β = type II (false reassurance) error rate, the risk of rejecting a good batch of observations = 0.1

$a = \ln([1 - \beta]/\alpha)$

$b = \ln([1 - \alpha]/\beta)$

$P = \ln(p_1/p_0)$

$Q = \ln([1 - p_0]/[1 - p_1])$

$s = Q/(P + Q) = 0.145$

$h_1 = a/(P + Q)$, upper ("alert") control limit (to detect an increase from p_0 to p_1) = 2.71

$h_0 = -b/(P + Q)$, lower (“reassurance”) control limit (to accept p_0) $= -2.71$

X_i denotes the outcome for procedure i, $X_i = 1$ if a failure is observed, and $X_i = 0$ if a success is observed. The Cumulative Sum T_i was calculated as

$$T_i = T_{i-1} + (X_i - s), \quad \text{with } T_0 = 0$$

The graph of the Cumulative Sum (T_i) was plotted against attempt number i to obtain the learning curve.

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