

## Main Article

Dr A Tang takes responsibility for the integrity of the content of the paper

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## Abstract

**Objectives.** To explore the factors associated with the operative duration for paediatric tracheobronchial foreign body removal by rigid bronchoscopy, and to analyse the learning curve for mastery of the rigid bronchoscopy skill.

**Methods.** A retrospective study was performed of paediatric cases of tracheobronchial foreign body removal by rigid bronchoscopy in our department from January 2007 to July 2019. Multivariate Cox regression analysis was used to analyse the factors associated with the operative duration. In addition, the learning curves for two doctors were evaluated by curve-fitting regression analysis.

**Results.** A total of 410 paediatric cases of tracheobronchial foreign body removal by rigid bronchoscopy were evaluated. The operative duration was significantly influenced by the skill of the doctor. The learning curves for both doctor A and doctor B demonstrated two typical phases: an initially rapidly changing learning phase followed by a steady consolidation phase.

**Conclusion.** The operative duration for paediatric tracheobronchial foreign body removal by rigid bronchoscopy was associated with the skill of the doctor. In order to fully master the rigid bronchoscopy technique, doctors should perform a minimum number of procedures to pass the learning phase and reach the consolidation phase.

## Introduction

Tracheobronchial aspiration of a foreign body is a life-threatening emergency in the paediatric population.<sup>1,2</sup> Rigid bronchoscopy can provide adequate airway control, satisfactory visualisation and easy manipulation of the targeted object.<sup>3</sup> It has been recommended as the procedure of choice for localising and removing a tracheobronchial foreign body.<sup>4</sup> Previous study results have suggested that more than 90 per cent of tracheobronchial foreign bodies can be removed by bronchoscopy with very few complications.<sup>4,5</sup> However, a lack of training on rigid bronchoscopy could result in missed and delayed diagnoses of a tracheobronchial foreign body.<sup>6</sup> Adequate training and practice are essential to ensure that performance of rigid bronchoscopy is appropriate for tracheobronchial foreign body removal and to avoid complications.<sup>7</sup>

Many countries have established standard guidelines and protocols for improving the procedural skills and competency of doctors.<sup>8–10</sup> It is well known that a learning curve, which typically starts with a steep ascending phase and reaches a plateau phase, applies to doctors during procedural training.<sup>11–13</sup> Many variables, such as the total number and complexity of the procedural steps, can affect this learning curve.<sup>14</sup> Surgeons need to pass the ascending phase and reach the plateau phase of the learning curve before they can perform procedures competently and independently. The learning curve for performing rigid bronchoscopy to remove a tracheobronchial foreign body has not been reported previously.

In the present study, we used operative duration as the outcome measure to investigate factors that affect performance of rigid bronchoscopy for paediatric tracheobronchial foreign body removal. We further analysed the learning curve for applying rigid bronchoscopy in such cases. We also discuss the implications of this learning curve in terms of training doctors' mastery of the tracheobronchial foreign body removal procedure.

## Materials and methods

### Study design and participants

We conducted a retrospective study of paediatric tracheobronchial foreign body removal performed by rigid bronchoscopy in our department between January 2007 and July 2019 and evaluated the factors that could influence the procedure. In addition, we analysed the learning curves for two otolaryngologists who had more than five years' experience in ENT surgical procedures. Before they began removing tracheobronchial foreign bodies

by rigid bronchoscopy independently, the two doctors practised as first assistants to their supervisors in more than 10 cases, to familiarise themselves with the surgical process and instruments. The study protocol was approved by the hospital ethics committee.

### Operative procedure

All diagnoses of tracheobronchial foreign body were confirmed by the history of foreign body inhalation, and chest X-ray or computed tomography (CT) examination. After successful administration of general anaesthesia without intubation, a rigid bronchoscope was introduced through the glottis and inserted into the trachea. The operator could look through the other side of the rigid bronchoscope for direct visualisation. Once the child was maintained on ventilation through the side port of the rigid bronchoscope by a high-frequency jet, the tracheobronchial foreign body was carefully clamped by the forceps and withdrawn together with the rigid bronchoscope. A second look at the airway was taken to confirm that no foreign body remained. If the patient's oxygen saturation dropped below 85 per cent or continued to decline, the surgical procedure was aborted and high-frequency or mask oxygen delivery was given.

Tracheostomy, thoracotomy or fibre-optic bronchoscopy was performed if removal of the tracheobronchial foreign body by rigid bronchoscopy failed. Foreign body residues or other post-operative complications were examined via post-procedural chest X-ray or CT examination.

### Outcome measures

We evaluated paediatric tracheobronchial foreign body removal performed by rigid bronchoscopy. The outcome measure was operative duration, representing the time from insertion of the rigid bronchoscope into the oral cavity to the final withdrawal of the rigid bronchoscope (including the interrupted time for maintaining ventilation). We studied the factors that could affect operative duration. These factors included gender, age, time from foreign body aspiration to operation, pre-operative imaging results, types and locations of tracheobronchial foreign bodies, degree of dyspnoea and surgeon experience. According to their shape and nature, the tracheobronchial foreign bodies were assigned to four types: round and hard, round and fragile, irregular and hard, and irregular and fragile. We also reported the complications, including intra-operative and post-operative hypoxaemia, pneumothorax, mediastinal emphysema, laryngeal oedema and pneumonia. Then, we analysed the learning curves for doctors A and B with operative duration as the outcome.

### Statistical analysis

Statistical analysis was conducted using SPSS software, version 19.0 (IBM, Armonk, New York, USA). Continuous data, presented as mean ( $\pm$  standard deviation) values, were analysed using the *t*-test. Categorical data, presented as percentages, were tested with the chi-square test. Cox regression analysis was used for multivariate correlation analysis. The learning curves for the removal of tracheobronchial foreign bodies by rigid bronchoscopy for doctors A and B were generated by curve-fitting regression analysis.<sup>15</sup> Appropriate oscillating sinusoidal curve models ( $y = \sin(x) - p / 2$ ) and logarithmic curve models ( $y = b \ln(x) + b_0$ ) were selected for the curve

**Table 1.** Cox regression analysis of operative duration

| Parameter   | OR    | 95% CI      | P-value   |
|---|-------|-------------|-----------|
| Sex   | 1.007 | 0.820–1.237 | 0.946     |
| Age   | 0.988 | 0.828–1.179 | 0.895     |
| Admission date  | 1.017 | 0.982–1.053 | 0.340     |
| Tracheobronchial FB type                              | 0.961 | 0.894–1.033 | 0.285     |
| Tracheobronchial FB location                          | 1.043 | 0.945–1.150 | 0.405     |
| Surgeon seniority                                     |       |             |           |
| – Attending surgeon (>5 years' surgical experience)   |       |             | Reference |
| – Associate professor (>8 years' surgical experience) | 0.571 | 0.437–0.745 | <0.001*   |
| – Professor (>10 years' surgical experience)          | 0.746 | 0.559–0.996 | 0.047*    |
| Degree of dyspnoea                                    | 1.087 | 0.960–1.230 | 0.189     |
| Onset time  | 1.109 | 0.993–1.239 | 0.067     |
| Pre-operative complication                            | 0.967 | 0.901–1.037 | 0.340     |

\*Indicates statistical significance ( $p < 0.05$ ). OR = odds ratio; CI = confidence interval; FB = foreign body

fitting. A trial-and-error approach (iterative method) was used to find the turning point of the curve. A *p*-value of less than 0.05 was considered statistically significant.

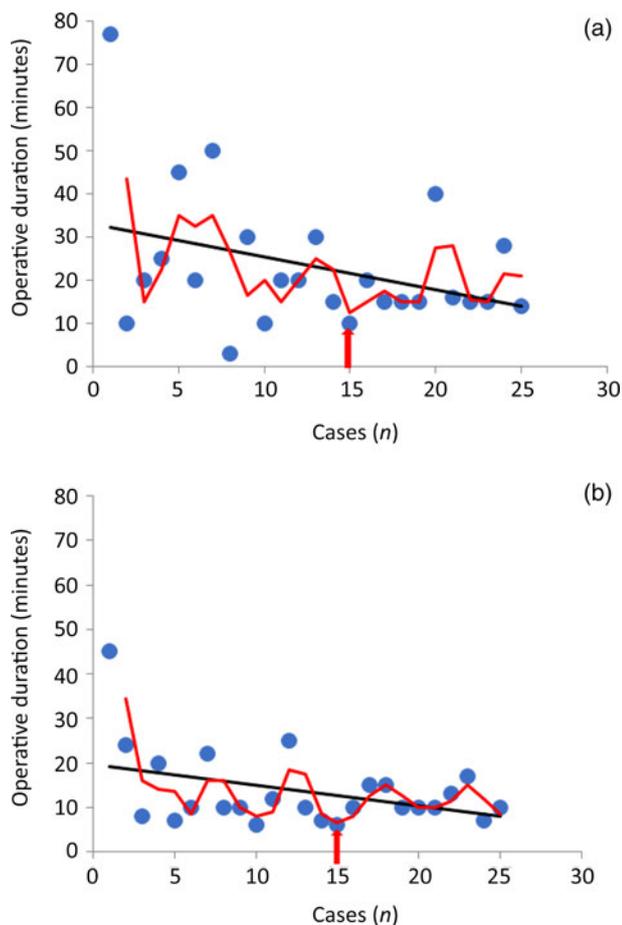
### Results

A total of 410 paediatric cases of tracheobronchial foreign bodies removed by rigid bronchoscopy between January 2007 and July 2019 were reviewed. Cox regression analysis showed that the operative duration was related to the surgeons' experience level (Table 1). Senior professional status ( $p < 0.001$ ) was associated with shorter operative duration.

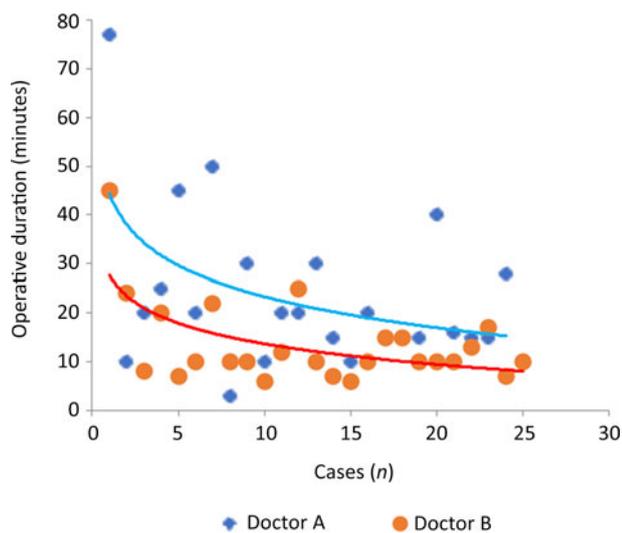
Both doctors A and B had more than five years but less than eight years of ENT operating experience. Therefore, we reviewed all cases, from the first to the last, of tracheobronchial foreign body removal performed by these two doctors, from among 410 total cases of tracheobronchial foreign body removal, to construct a learning curve. In total, 50 cases were selected for the study (25 cases for doctor A and 25 for doctor B). No complication or foreign body residue occurred in the cases treated by either doctor A or doctor B. Therefore, the learning curves for the two doctors were compared in terms of operative duration.

Learning curve analysis showed a negative relationship between the operative duration and the accumulated number of procedures for both doctors (Figure 1). The operative duration shortened as the total number of procedures increased. In addition, the amplitudes of sinusoidal curve oscillations decreased as the total number of procedures increased, and tended to decrease steadily in the later stage. From the scatter plots, the turning point from a rapid decline to a slow decline in operative duration, for both doctors A and B, appeared around the 15th case, which was considered the inflection point of the curve.

The logarithmic curves for the two doctors are shown in Figure 2. With the accumulation of procedure numbers, the



**Fig. 1.** Relationships between operative duration and accumulated number of procedures for doctors A (a) and B (b). Black lines represent linear regression curves. Red lines represent moving parallel curve. Arrows show the inflection points of the curves, which demonstrate the turning point from a rapid to a slow decline in operative duration.



**Fig. 2.** Logarithmic learning curves for doctors A and B. Equations: (1) doctor A:  $y = -9.758\ln(x) + 45.360$  ( $R^2 = 0.253$ ,  $p = 0.010$ ); and (2) doctor B:  $y = -6.117\ln(x) + 27.753$  ( $R^2 = 0.3576$ ,  $p = 0.002$ ).

operative durations showed a sharp decline in the early stage (the learning phase) for both doctors A and B, and then began to decline slowly beyond about the 15th case (the consolidation phase). An iterative method was also applied to calculate the degree of dispersion of operative time for the two

**Table 2.** Distribution of operative times for the two surgeons

| Cut-off point | Operative time before cut-off point (mean $\pm$ SD; minutes) | Operative time after cut-off point (mean $\pm$ SD; minutes) | P-value |
|---------------|--|---|---------|
| Case 5        | 28.10 $\pm$ 21.850   | 16.58 $\pm$ 9.375   | 0.134   |
| Case 6        | 25.92 $\pm$ 20.523   | 16.66 $\pm$ 9.547   | 0.155   |
| Case 7        | 27.36 $\pm$ 19.998   | 15.58 $\pm$ 7.912   | 0.050   |
| Case 8        | 26.44 $\pm$ 19.138   | 15.32 $\pm$ 7.686   | 0.039   |
| Case 9        | 25.72 $\pm$ 18.419   | 15.03 $\pm$ 7.412   | 0.029   |
| Case 10       | 23.95 $\pm$ 18.268   | 15.50 $\pm$ 7.403   | 0.062   |
| Case 11       | 23.23 $\pm$ 17.577   | 15.46 $\pm$ 7.594   | 0.064   |
| Case 12       | 23.17 $\pm$ 16.813   | 14.92 $\pm$ 7.584   | 0.035   |
| Case 13       | 22.92 $\pm$ 16.395   | 14.50 $\pm$ 7.169   | 0.023   |
| Case 14       | 22.07 $\pm$ 16.120   | 14.82 $\pm$ 7.314   | 0.040   |
| Case 15       | 21.13 $\pm$ 15.967   | 15.50 $\pm$ 7.302   | 0.099   |
| Case 16       | 20.75 $\pm$ 15.569   | 15.56 $\pm$ 7.524   | 0.119   |
| Case 17       | 20.41 $\pm$ 15.152   | 15.63 $\pm$ 8.007   | 0.151   |
| Case 18       | 20.11 $\pm$ 14.766   | 15.71 $\pm$ 8.597   | 0.302   |
| Case 19       | 19.71 $\pm$ 14.476   | 15.97 $\pm$ 9.166   | 0.336   |

SD = standard deviation

surgeons and to confirm the inflection point of the curve. With this method, we found that the operation times, both mean and standard deviation values, remained essentially unchanged beyond the 15th case (cut-off point = 14th case), indicating that the surgeon was then skilled in the technique (Table 2). The curve for doctor B was lower than that for doctor A in both the learning stage and the consolidation stage, indicating that doctor B required fewer learning procedures than doctor A to reach the consolidation stage. The logarithmic curves for the two doctors did not show a significant stable period after the slow decline.

**Discussion**

Tracheobronchial aspiration of a foreign body is a life-threatening paediatric emergency. It is important for otolaryngologists to quickly remove the tracheobronchial foreign body in order to save the patient’s life. Therefore, otolaryngologists should receive appropriate training to adequately understand the knowledge and master the clinical skills of rigid bronchoscopy, which is the recommended procedure for tracheobronchial foreign body removal.

Studies on surgery learning curves have focused mostly on the endoscopic technique or robotic surgery.<sup>16–18</sup> No study on learning curves for rigid bronchoscopy performed for tracheobronchial foreign body removal from paediatric patients has been reported previously. We conducted the present study to analyse the factors associated with paediatric tracheobronchial foreign body removal by rigid bronchoscopy and to explore the learning experience for the procedure, with the goal of providing a preliminary guideline for doctors, especially those in primary hospitals, who plan to perform this life-saving procedure.

Measured outcomes for surgical skill learning curves include operative duration, bleeding, complications and length of hospital stay.<sup>19,20</sup> In the present study, we used operative

duration as the outcome measure, because the time taken to remove a tracheobronchial foreign body has a direct impact on the blood oxygen of the patient, and delayed tracheobronchial foreign body removal could result in death.<sup>21</sup> We did not include the length of the hospital stay in the learning curve, because all children in this study were discharged within 48 hours after the removal of the foreign body. We also did not use foreign body residues or complications as the outcome measures for the learning curves, because no complication or retention of foreign body residue occurred in the included cases.

We initially conducted multivariate Cox regression analysis to evaluate the effects of gender, age, type and location of tracheobronchial foreign body, and doctor experience on the operative duration. The results showed that doctor experience could influence the operative duration. Both doctors A and B had more than five years of ENT operation experience, the learning curves for the cumulative number of procedures and the duration of surgery were analysed separately.

From the learning curves generated in this study, we observed that the operative duration decreased rapidly during the initial stage (the learning phase) and then reached a plateau even as the accumulated number of procedures increased (the consolidation phase). This was consistent with the learning curves described previously for other procedures.<sup>11,13,20</sup> For both doctors, the operative duration decreased relatively rapidly until they reached approximately the 15th case (the inflection point of the curve). Further accumulation of procedure numbers beyond the 15th case was not associated with a more rapid reduction in operative duration. Operative duration can be the best indicator of familiarity with and/or mastery of a technique.<sup>15,22</sup> Therefore, we considered that, under the current training models in our department, the minimum number of rigid bronchoscopy procedures for tracheobronchial foreign body removal in the learning phase should be 15 cases. Doctors should perform at least 15 rigid bronchoscopy procedures to reach the inflection point in order to master the clinical skills. In other hospitals and in different countries, the learning curve might have a different inflection point. Each department may need to determine its own inflection point in the learning curve based on previous training outcomes to guide further training of new doctors to provide rigid bronchoscopy.

In our study, the surgical learning curve for doctor B was lower than that for doctor A in both the learning phase and the consolidation phase, indicating that doctor B needed fewer learning cases than doctor A to reach the consolidation stage. This suggested individual variation in mastering this surgical procedure. Such learning variation among trainees has been reported previously.<sup>23,24</sup> It might be a result of the different baseline knowledge of the doctors who received training. It could also depend on the co-operation from the assistants, anaesthesiologists and surgical nurses during the procedures. The influence of anaesthesiologists and surgical nurses on the learning curves requires further research. The variation in the learning curves also suggests that a training protocol might be individualised to fit the requirements of different trainees.

In order to improve the learning period for rigid bronchoscopy performed for paediatric tracheobronchial foreign body removal, we recommend the following protocols during training. First, doctors should familiarise themselves with the anatomical structures and physiology of airways, and remain alert to rule out the presence of a suspected airway foreign body in a

child. Second, before becoming an independent operator, a doctor must perform an adequate number of rigid bronchoscopy procedures as an assistant, to master the surgical steps and rescue methods, and be able to calmly, quickly, accurately and effectively address possible complications during the procedure. Third, before the procedure, doctors should make operative plans and prepare appropriate bronchoscopes and forceps, based on the patient's medical history, imaging results and foreign body type. Fourth, each department should establish its own learning curve for rigid bronchoscopy based on previous training outcomes to identify the inflection point, which helps to identify the minimum number of procedures needed to pass the learning phase and reach the consolidation phase. Fifth, in the learning phase of the learning curve (i.e. during procedures for the first 15 cases in our department), doctors should realise their limitations and seek appropriate guidance from their supervisors during the procedures, especially for difficult and potentially life-threatening cases. Sixth, in the consolidation phase, doctors should continue performing procedures to maintain their skills. Seventh, the selection of appropriate assistants, anaesthesiologists and surgical nurses is important to ensure the success of the rigid bronchoscopy procedures.

- This is the first study of learning curves for rigid bronchoscopy performed for tracheobronchial foreign body removal in paediatric patients
- The learning curve comprised an initial learning phase followed by a consolidation phase
- Doctors should perform a certain number of procedures to master the technique in the learning phase
- They should continue performing the procedure to maintain their skills in the consolidation phase

The limitations of the present study include its single-centre design and very small sample size for analysis of the learning curve. Its retrospective design also introduced inherited biases into the results. All these factors could limit the generalisation of the results to other hospitals. Further prospective studies in more hospitals need to be performed to verify our results.

## Conclusion

The operative time required to remove a paediatric tracheobronchial foreign body by rigid bronchoscopy was associated with the skill level of the doctor. The learning curve for rigid bronchoscopy performed for paediatric tracheobronchial foreign body removal included an initial learning phase followed by a consolidation phase. Doctors should perform a certain number of procedures in the learning phase to master the technique. In the consolidation phase, doctors should continue performing the procedure to maintain their skills.

**Competing interests.** None declared

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