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Original Research Article

Learning Curves and Competency Thresholds for Mannequin-Based Fiberoptic Intubation Simulation Among Anesthesia Trainees: A Multicenter Prospective Educational Study

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Abstract

Background: Fiberoptic intubation is an essential skill in difficult airway management and remains a key competency in anesthesiology training. However, acquisition of proficiency requires repeated practice, structured supervision, and objective competency assessment. Simulation-based training using mannequins/dummies provides a safe and controlled environment for skill development before clinical application. Despite increasing use of simulation training, standardized learning curves and competency thresholds for fiberoptic intubation among anesthesia trainees remain inadequately defined.

Aim and Objectives: To evaluate learning curves and competency thresholds for mannequin-based fiberoptic intubation simulation among anesthesia trainees and assess improvement in procedural performance, first-pass success rate, procedural errors, and skill retention following structured simulation-based training.

Methodology: This multicenter prospective interventional educational study was conducted among 60 participants, including postgraduate residents, senior residents, assistant professors, and associate professors from participating anesthesiology departments. Baseline assessment of mannequin-based fiberoptic intubation performance was performed prior to training. Participants subsequently underwent standardized didactic teaching, faculty demonstration, and repeated supervised mannequin/dummy-based fiberoptic intubation simulation sessions. Pre- and post-training assessments included time to successful intubation, first-pass success rate, procedural errors, simulated airway trauma, and need for assistance. Learning curves and competency thresholds were analyzed using cumulative sum (CUSUM) analysis.

Results: The majority of participants achieved predefined competency after 6–10 supervised mannequin-based simulation attempts. Mean intubation time decreased significantly from 128.4 ± 32.6 seconds during baseline assessment to 58.7 ± 16.4 seconds after training ($p<0.001$). First-pass success rate improved from 36.7% pre-training to 88.3% post-training ($p<0.001$). Procedural error score decreased from 5.8 ± 1.7 to 1.9 ± 0.8, while simulated airway trauma score reduced from 3.4 ± 1.1 to 1.1 ± 0.5 following training. Participants with prior videolaryngoscopy experience achieved competency significantly earlier than participants without previous airway instrumentation exposure.

Conclusion: Structured mannequin-based fiberoptic intubation simulation training significantly improves procedural competency, reduces intubation time, improves first-pass success rate, and decreases procedural errors among anesthesia trainees. Identification of objective learning curves and competency thresholds may help standardize airway management training protocols and improve preparedness for difficult airway management in anesthesiology practice.

Keywords: Fiberoptic intubation; Simulation training; Learning curve; Competency threshold; Difficult airway; Airway mannequin; Anesthesia education; CUSUM analysis.

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Introduction

Airway management is a critical responsibility of anesthesiologists, and failure to secure the airway remains an important cause of anesthesia-related morbidity and mortality. Fiberoptic intubation is considered the gold standard technique for anticipated difficult airway management because it allows continuous visualization of airway structures while minimizing airway trauma [1].

However, fiberoptic intubation is technically demanding and requires advanced psychomotor coordination, bronchoscope handling skills, and repeated supervised practice for acquisition of competency [1]. Traditional apprenticeship-based learning in real patients is limited by patient safety concerns, inconsistent clinical exposure, and procedural stress among trainees. Therefore, simulation-based training using mannequins and airway simulators has emerged as a safer and more structured educational approach for teaching fiberoptic intubation skills [2].

Several studies have demonstrated that simulation-based training improves fiberoptic intubation performance and procedural confidence among anesthesia trainees. Ovassapian A et al. reported improved awake fiberoptic intubation performance following simulator-based training [3]. Similarly, Goldmann K et al. demonstrated that airway simulators facilitated acquisition of bronchoscopy skills among anesthesia residents [4]. Cai Y et al. further demonstrated progressive competency acquisition during repeated supervised fiberoptic intubation attempts using cumulative sum (CUSUM) analysis [1]. Likewise, Ji SH et al. reported significant improvement in intubation performance during repeated simulation-based pediatric airway mannequin training [5].

Despite increasing use of simulation-based airway education, limited multicenter data are available regarding standardized competency thresholds and learning curves for fiberoptic intubation among anesthesia trainees [1,5]. Therefore, the present study was conducted to evaluate learning curves and determine competency thresholds for mannequin-based fiberoptic intubation simulation among anesthesia trainees across multiple teaching institutes.

Aim: To evaluate learning curves and determine competency thresholds for mannequin-based fiberoptic intubation simulation among anesthesia trainees across multiple teaching institutes.

Objectives

Primary Objective: To determine the number of mannequin-based simulation attempts required for anesthesia trainees to achieve predefined competency in fiberoptic intubation.

Secondary Objectives

1. To assess improvement in intubation performance, including intubation time, first-pass success rate, overall success rate, procedural errors, and simulated airway trauma following structured simulation-based training.
2. To evaluate the influence of prior videolaryngoscopy experience on competency acquisition and learning curves.
3. To assess retention of acquired fiberoptic intubation skills and variability in competency acquisition among participating training institutes.

Methodology

Study Design: This multicenter prospective interventional educational study was conducted with pre-training and post-training assessment.

Study Setting: The study was conducted in the Departments of Anesthesiology of participating tertiary care teaching institutes equipped with airway simulation laboratory facilities.

Study Duration: The study was conducted over a period of 12 months after obtaining approval from the Institutional Ethics Committees of participating institutes.

Study Population: Participants involved in airway management training, including postgraduate residents, senior residents, assistant professors, and associate professors from participating anesthesiology departments, were included in the study.

Sample Size: Sample size was determined based on previously published studies evaluating competency achievement and learning curves in fiberoptic bronchoscopy-guided intubation training among anesthesia trainees [1]. Considering feasibility of recruitment, multicenter study design, and possible attrition, a final sample size of 60 participants was included.

Inclusion Criteria

- Participants involved in airway management training
- Participants willing to provide written informed consent
- Participants with limited or no formal fiberoptic intubation simulation training

Exclusion Criteria

- Participants with extensive prior fiberoptic intubation experience
- Participants unwilling to participate
- Incomplete participation in simulation sessions

Study Procedure

Pre-Training Assessment: Baseline demographic details and prior airway management experience were recorded before training. Initial mannequin-based fiberoptic intubation performance was assessed using:

- Time to successful intubation
- First-pass success rate

- Procedural errors
- Simulated airway trauma
- Need for assistance

Training Intervention: All participants underwent standardized mannequin/dummy-based fiberoptic intubation simulation training under faculty supervision. Training included:

1. Didactic teaching session
2. Faculty demonstration of fiberoptic intubation technique
3. Repeated supervised mannequin-based practice sessions

Post-Training Assessment: Following completion of training, reassessment was performed using the same competency assessment parameters. Follow-up reassessment was performed after 3–6 months to evaluate skill retention.

Outcome Measures

Primary Outcome

- Number of simulation attempts required to achieve predefined competency

Secondary Outcomes

- Improvement in intubation time
- Improvement in first-pass success rate
- Reduction in procedural errors
- Skill retention during follow-up assessment
- Variability in competency acquisition among institutes

Statistical Analysis: Quantitative variables were expressed as mean ± standard deviation, while qualitative variables were expressed as frequency and percentage. Pre- and post-training comparisons were analyzed using paired statistical tests. Learning curves were evaluated using cumulative sum (CUSUM) analysis. A p-value of <0.05 was considered statistically significant.

Results

A total of 60 participants from multiple tertiary care teaching institutes were included in the study. Participants included postgraduate residents, senior residents, assistant professors, and associate professors involved in airway management training. Structured mannequin-based fiberoptic intubation simulation training demonstrated significant improvement in procedural performance following repeated supervised attempts.

Table 1: Baseline Characteristics of Participants

Variable	Frequency (n=60)	Percentage (%)
Gender		
Male	38	63.3
Female	22	36.7
Designation		
Postgraduate Residents	32	53.3
Senior Residents	14	23.3
Assistant Professors	9	15.0
Associate Professors	5	8.4
Previous Videolaryngoscopy Experience		
Yes	41	68.3
No	19	31.7
Previous Fiberoptic Intubation Exposure		
Yes	12	20.0
No	48	80.0

The majority of participants were postgraduate residents, and most participants had prior videolaryngoscopy exposure but limited previous fiberoptic intubation experience.

Table 2: Comparison of Pre-Training and Post-Training Performance Parameters

Parameter	Pre-Training Mean ± SD	Post-Training Mean ± SD	p-value
Time to Successful Intubation (seconds)	128.4 ± 32.6	58.7 ± 16.4	<0.001
First-Pass Success Rate (%)	36.7	88.3	<0.001
Procedural Error Score	5.8 ± 1.7	1.9 ± 0.8	<0.001
Simulated Airway Trauma Score	3.4 ± 1.1	1.1 ± 0.5	<0.001
Need for Faculty Assistance (%)	81.7	18.3	<0.001

A statistically significant reduction in intubation time, procedural errors, simulated airway trauma, and need for faculty assistance was observed following structured mannequin-based simulation training. First-pass success rate improved markedly from 36.7% during baseline assessment to 88.3% following repeated supervised simulation attempts.

Table 3: Competency Achievement According to Number of Simulation Attempts

Number of Attempts	Participants Achieving Competency (n)	Percentage (%)
≤5 Attempts	9	15.0
6–10 Attempts	27	45.0
11–15 Attempts	18	30.0
>15 Attempts	6	10.0

The majority of participants (45%) achieved predefined competency after 6–10 mannequin-based simulation attempts, while only 10% required more than 15 attempts to achieve competency.

Table 4: Association of Prior Videolaryngoscopy Experience With Competency Achievement

Prior Videolaryngoscopy Experience	Mean Attempts Required for Competency	p-value
Yes (n=41)	8.2 ± 2.6	0.002
No (n=19)	12.1 ± 3.4	

Participants with prior videolaryngoscopy experience achieved competency significantly earlier compared to participants without previous airway instrumentation exposure.

Table 5: Follow-Up Skill Retention Assessment at 3–6 Months

Parameter	Immediate Post-Training	Follow-Up Assessment	p-value
First-Pass Success Rate (%)	88.3	81.7	0.12
Mean Intubation Time (seconds)	58.7 ± 16.4	66.9 ± 18.1	0.02
Procedural Error Score	1.9 ± 0.8	2.3 ± 0.9	0.03

Most participants retained satisfactory fiberoptic intubation performance during follow-up reassessment. Although mild increase in intubation time and procedural error score was observed during follow-up, overall competency remained satisfactory, indicating good retention of acquired simulation-based airway management skills.

Discussion

The present multicenter prospective educational study demonstrated significant improvement in fiberoptic intubation performance following structured mannequin-based simulation training among anesthesia trainees. In the present study, 45% of participants achieved predefined competency after 6–10 supervised simulation attempts, while 30% achieved competency after 11–15 attempts. Similar findings were reported by Cai Y et al. [1], who observed competency achievement after approximately 15 supervised procedures using cumulative sum (CUSUM) analysis. Likewise, Konrad C et al. [7] demonstrated progressive improvement in procedural competency with repeated supervised practice.

The present study showed a significant reduction in mean intubation time from 128.4 ± 32.6 seconds to 58.7 ± 16.4 seconds following training ($p<0.001$). Similar reduction in procedural time was reported by Naik VN et al. [6] and Ji SH et al. [5], who demonstrated improved bronchoscope handling and faster intubation following repeated simulation-based practice.

First-pass success rate improved markedly from 36.7% pre-training to 88.3% post-training in the present study. Comparable improvement in successful fiberoptic-guided intubation was reported by Ji SH et al. [5] and Ovassapian A et al. [3]. Additionally, procedural error score and simulated airway trauma score decreased significantly after training, similar to observations reported by Goldmann K et al. [4] and Naik VN et al. [6].

Participants with prior videolaryngoscopy experience achieved competency significantly earlier than inexperienced participants, which is consistent with findings reported by Konrad C et al. [7]. Follow-up reassessment also demonstrated satisfactory retention of acquired fiberoptic intubation skills after 3–6 months, supporting the role of repeated spaced simulation practice in airway management training.

Overall, the findings of the present study are consistent with previously published simulation-based airway education studies and further support the effectiveness of structured mannequin-based fiberoptic intubation simulation training in improving airway management competency among anesthesia trainees.

Conclusion

Structured mannequin-based fiberoptic intubation simulation training significantly improved procedural competency among anesthesia trainees by reducing intubation time, improving first-pass success rate, and decreasing procedural errors. Most participants achieved predefined competency after 6–10 supervised simulation attempts, while prior videolaryngoscopy experience was associated with faster competency acquisition. The study supports simulation-based airway training as a safe and effective educational method for developing

fiberoptic intubation skills and establishing standardized competency thresholds in anesthesiology training.

Limitations

1. The study was conducted using mannequin-based simulation training, which provides a standardized and controlled learning environment but may differ from certain dynamic clinical airway situations.
2. Participants had varying levels of prior airway management exposure, which may have influenced the speed of competency acquisition.
3. Follow-up assessment was limited to short-term skill retention after simulation-based training.

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