Enhancing Team Competencies and Self-efficacy in Airway Management Through the PDCA Cycle: A Simulation-based Study in Standardized Anesthesiology Resident Training

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Abstract: Background: Effective management of difficult airway scenarios in healthcare demands continual skill development among teams. The Plan-Do-Check-Act (PDCA) cycle presents a promising methodology for bolstering team competencies via iterative enhancement processes. Methods: This study explored the effectiveness of healthcare teams trained using the PDCA cycle compared to those trained with standard protocols in simulated airway management scenarios. Team performance was assessed using the team skill checklist for airway management algorithm. Both groups of anesthesiology residents underwent evaluations before and after training to measure changes in their self-efficacy levels. Results: The PDCA group demonstrated significantly higher mean checklist skill scores on the simulation scenario test (89.50) compared to the Standard group (82.50), indicating enhanced technical proficiency. Moreover, the PDCA group exhibited a substantial increase in self-efficacy (27.81%) compared to the Standard group (19.82%). Conclusion: Implementing the PDCA cycle enhances technical proficiency and cultivates a culture of continuous learning and development among healthcare teams. By integrating PDCA into training protocols, teams gain a structured framework for ongoing evaluation, adaptation, and skill enhancement, particularly in challenging airway management scenarios. These results underscore the PDCA cycle's crucial role in advancing team dynamics, improving personal self-efficacy, and optimizing readiness for critical healthcare situations.

Keywords: Plan–Do–Check–Act cycle; airway management; simulation training; medical education; anesthesia

1. Introduction

A difficult airway refers to situations in which a healthcare provider who is appropriately skilled in airway management encounter anticipated or unforeseen obstacles or failures [1]. Challenges may arise in several procedures such as facemask ventilation, laryngoscopy, supraglottic airway ventilation, tracheal intubation, extubation, and invasive airway interventions [2]. In its most severe cases, anesthesiologists may encounter a failed airway scenario, where they are unable to effectively ventilate an anesthetized patient using non-surgical methods like a facemask or supraglottic airway, or successfully intubate with an endotracheal tube. This critical situation, often referred to as the "cannot intubate, cannot oxygenate" (CICO), mandates urgent intervention through invasive measures [3]. Managing complex airway situations is critical due to potential complications like cardiopulmonary arrest, hypoxic brain damage, and death. Evidence indicates that challenges in airway management significantly contribute to perioperative morbidity and mortality rates.

Indeed, airway management stands as a critical clinical skill for anesthesiologists, necessitating their capability to secure the airway employing a diverse array of methods rapidly and efficiently. Continual training and resource accessibility are essential for effective management and improved patient outcomes, particularly during the early stages of education. The simulation-based training has been proven effective in enhancing the skills of anesthesia residents in airway management, improving both their technical proficiency and non-technical abilities in this crucial area of patient care [4, 5]. However, while simulation based-training offers numerous benefits for airway management, it also presents certain challenges.

The Plan-Do-Check-Act (PDCA) cycle is a widely recognized framework utilized for problem-solving, process enhancement, and organizational advancement across various industries, including medical education. It can significantly improve teaching methodologies, curriculum development, and overall educational quality. The cycle consists of four sequential stages: 1) plan: a comprehensive understanding of the problem, setting clear objectives, and formulating strategic plans; 2) do: implementing the strategic plan after developing well-defined procedures; 3) check: continuous assessment and examination of execution outcomes are conducted to confirm goal attainment, while identifying strengths, weaknesses, opportunities, and threats aids in recognizing areas requiring improvement; 4) act: informed by assessment findings, determining subsequent actions to refine further, thus perpetuating a cycle of continuous improvement. To date, limited data exist regarding the effects of the PDCA cycle on airway management. Therefore, the primary objective of this study is to investigate whether the implementation of the PDCA cycle can enhance the effectiveness of simulation training and improve performance.

2. Methods

2.1 Participants

Between July and December 2023, a prospective controlled study was carried out at the Department of Anesthesiology, The First Affiliated Hospital of Nanjing Medical University. The study involved residents who were applying for the "Difficult Airway Management" medical education program. Before the initial training, participants anonymously volunteered and underwent interviews that encompassed their specialty experience, difficult airway management, involvement in simulation training, and prior difficult airway training. Inclusion criteria for the study consisted of: (1) willingness to participate; (2) absence of prior experience in simulated teaching; (3) agreement to comply with the study protocol and guidelines for the entire research duration; (4) completion of necessary training or coursework required for study participation. Exclusion criteria encompassed: (1) unwillingness to continue in the research; (2) previous participation in similar research studies. All eligible participants provided consent and were randomly assigned to either the standard simulation-based training (Standard group) or PDCA simulation-based training (PDCA group).

2.2 Study design

In a simulated clinical setting, a 71-year-old female undergoing laparoscopic gastrectomy for gastric cancer encounters a challenging airway emergency. Following standard monitoring, anesthesia induction includes the administration of etomidate 20 mg, sufentanil 10 μg, and intravenous rocuronium bromide 50 mg. Despite successful mask ventilation after loss of consciousness, direct laryngoscopy reveals only a partial view of the epiglottis, with subsequent unsuccessful tracheal intubation attempts. Trainees adhere to a structured Standard Operating Procedure (SOP) based on established guidelines [6], involving sequential steps such as adjusting positioning, applying external laryngeal compression techniques, utilizing visual laryngoscopy, and incorporating other auxiliary instruments. If intubation fails after three primary attempts with an additional attempt (3+1), intubation failure is declared, and a switch to face mask ventilation is initiated. Successful mask ventilation prompts reassessment, while failed attempts necessitate the use of a supraglottic airway device (SAD) for ventilation. In a CICO scenario, emergency invasive airway ventilation procedures are implemented. The SOPs prioritize patient safety and teamwork, empowering trainees to effectively manage complex airway emergencies.

The PDCA group utilized the same case as a simulation scenario for their training in managing difficult airways. The training followed a systematic approach, adhering to the four phases of the cycle. (1) Plan: The central training assessment team will be established to define the training objectives and determine the composition of personnel involved in the training program. Identification of primary hurdles in airway emergency management will guide the creation of detailed learning objectives and simulation scenarios. These scenarios will integrate the SOP and ensure the availability of necessary equipment. (2) Do: Trainees will engage in a comprehensive learning process that includes self-directed study, didactic lectures, and collaborative group discussions. This phase will cover a diverse array of topics: evaluating and preparing for managing difficult airways, mastering procedural techniques, ensuring the proper utilization and maintenance of complex airway tools, and critically analyzing case studies that highlight successful approaches to managing challenging airways. Subsequently, trainees will actively engage in simulation exercises designed to replicate authentic scenarios involving complex airway challenges. These simulations will rigorously enforce adherence to the SOPs, ensuring trainees effectively apply their acquired skills. Throughout these exercises, there will be a strong emphasis on fostering effective communication, coordination, and cooperation among trainees to optimize learning outcomes. (3) Check: Post-simulation, conduct a comprehensive debriefing session. Evaluate trainees' performance based on the SOP and learning objectives, identifying both strengths and areas necessitating improvement. Scrutinize technical prowess, communication efficacy, and decision-making aptitude. (4) Act: Provide constructive feedback, accentuating strengths and outlining areas for enhancement. Offer supplementary coaching and resources to address identified gaps. Modify the simulation scenario or SOP if warranted based on performance insights. Iteratively repeat simulations and the PDCA cycle until proficiency in managing airway emergencies is attained. This refined approach ensures continual enhancement in simulation-based airway emergency management.

2.3 Measurements and end point assessment

Both groups underwent pre- and post-training evaluations to assess their self-efficacy, encompassing five key areas: analytical skills, emergency response proficiency, teamwork abilities, expertise in managing difficult airways, and confidence in real clinical practice. These competencies were evaluated on a visual analog scale (VAS) from 0 to 10, with a cumulative allocation of 50 points spread across the five criteria. Following a four-week teaching period, all students participated in a simulation scenario test with a new case. Each team's performance was evaluated based on a 20-item team skill checklist (Table 1), with each item scored out of 5 points and a maximum total score of 100.

The primary endpoint of the study was the team skills score obtained from the simulation scenario test checklist, with secondary endpoints including improvements in self-efficacy scores compared to pre-training levels. The delta self-efficacy score (Δ-score) was calculated as the difference between post-training and pre-training scores. The Δ-score (%) was calculated using the formula: Δ-score (%) = (Score post-training – Score pre-training) / Score pre-training × 100%.

Table 1. 20-Item Team Skill Checklist for Airway Management Algorithm

Call for help
Difficult airway cart
Plan A: Intubation
Maintain ventilation and oxygenation
Positioning
A maximum of three attempts laryngoscopy (3+1)
External laryngeal manipulation
Adjuncts (Bougie/stylet/lightwand/ bronchofibroscopy)
If successful, confirm correct placement
If failed, declare “failed intubation”
Plan B: SAD
Maintain ventilation and oxygenation
Use second-generation SAD
A maximum of three attempts at SAD insertion
If successful, stop and think
If failed, declare “failed SAD ventilation”
Plan C: Mask ventilation
Attempt at Mask ventilation
Two-person ventilation
Adjuncts (Nasopharyngeal and oropharyngeal airway)
If successful, wake the patient up
If failed, declare “CICO”
Plan D: Emergency front-of-neck access
Cricothyrotomy

2.4 Statistical analysis

Statistical analysis was carried out using SPSS version 26, and graphical data were generated using GraphPad Prism version 10. Demographic parameters were compared between the groups. The normality of all variables was assessed using the Kolmogorov-Smirnov test. Normally distributed numerical data are presented as mean ± standard deviation (SD), while non-normally distributed data are presented as medians with 25–75% interquartile ranges (IQRs), and categorical data are presented as proportions. Student’s t-test was utilized for normally distributed data, while Pearson's chi-squared test was applied for categorical data. The Whitney–Mann U-test was conducted to assess to assess the difference in checklist team skills scores between the two groups. Within each group, paired t-tests were utilized to compare the pre-training and post-training outcomes. To compare the differences between the two groups’ post-training self-efficacy scores, analysis of covariance (ANCOVA) was conducted by using the pre-training scores as the covariate. A difference was considered significant if the p-value was less than 0.05 ($\alpha < 5\%$).

3. Results

A total of 81 subjects were enrolled in the study. Participants were predominantly male (54.3%) with a mean age of 26.28 ± 2.41 years. Each group was divided into 12 subgroups of 3 to 4 students. There were no significant differences in these baseline characteristics between the Standard and PDCA group. (Table 2).

Table 2. Comparison of Baseline Characteristics

Group	N	Age	Gender (M/F)	Postgraduate year (PGY 1/2/3)
Standard group	39	25.84±2.20	24/15	13/16/10
PDCA group	42	16.02±2.73	20/22	16/9/17
t/χ2	NA	1.09	1.58	3.98
p-value	NA	0.75	0.21	0.14

In Figure 1, the overall differences in checklist skill scores on the simulation scenario test are depicted, showing that the PDCA group significantly outperformed the Standard group [89.50 (87.00-91.00) vs. 82.50 (81.25-86.50); $p<0.01$]. There were no significant differences in pre-training self-efficacy scores between the two groups. Both groups demonstrated substantial improvement from their respective pre-test scores following training. Importantly, the PDCA group exhibited greater progress compared to the Standard group, with a Δ-score (%) of 27.81%±13.07% for PDCA and 19.82%±7.45% for Standard ($p<0.01$) (Table 3). After adjusting for relevant covariates, a statistically significant difference in performance between the two groups was confirmed (Table 4).

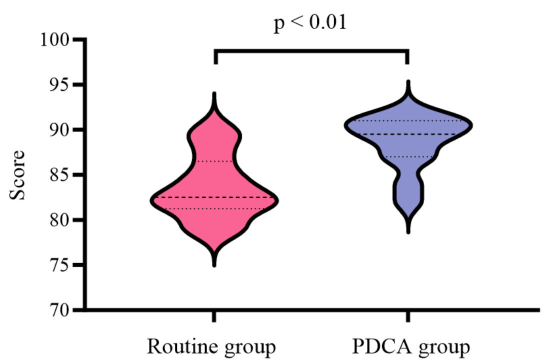

Figure 1. Comparison of Overall Checklist Skill Scores on the Simulation Scenario Test

Table 3. Comparison of Pre- and Post-Training Self-Efficacy Scores

Self-efficacy score	Pre-training sore	Post-training score	Δ-score	Δ-score(%)	T_paired	p-value
Standard group	30.69±3.60	36.74±4.61	6.05±2.36	19.82%±7.45%	-16.00	<0.01
PDCA group	30.95±4.44	39.21±4.39	8.26±3.98	27.81%±13.07%	-17.36	<0.01
t	-0.29	-2.46	-3.60	-3.34		
p-value	0.77	0.02	<0.01	p<0.01		

Table 4. Covariate Adjustment for Post-Training Self-Efficacy Scores.

Self-efficacy score	Post-training score (Actual)	Post-training score (Adjusted)	F	p-value
Standard group	36.74±4.61	36.86±0.44	13.53	<0.01
PDCA group	39.21±4.39	39.10±0.42		

4. Discussion

Our findings underscore the efficacy of the PDCA cycle in enhancing team skills during challenging airway simulation scenarios. Participants in the PDCA group achieved a remarkable mean score of 89.50, significantly surpassing the Standard group's mean score of 82.50. This highlights the positive impact of adopting the PDCA approach on task accuracy and efficiency. Both groups reported enhanced self-efficacy following simulation-based training. Importantly, the PDCA group exhibited a substantial improvement with a Δ-score (%) of 27.81%, compared to the Standard group's Δ-score (%) of 19.82%. Higher self-efficacy, as demonstrated in our study, reflects an increased capacity for effective behavior management and role competence among participants. This significant difference emphasizes the value of integrating the PDCA method into training programs, fostering continuous improvement, encouraging reflective practice, and enabling targeted adjustments to optimize performance.

The PDCA group training program is distinguished by its effective utilization of the PDCA cycle as the central mechanism for controlling difficult airway training. Our program places a strong emphasis on quality control and management, ensuring that trainees have a structured approach to improving their skills. The PDCA cycle's continuous monitoring of process and result quality enables detailed analysis of each step, promoting a culture of continuous improvement [7, 8]. Within the PDCA cycle, the check process holds utmost importance as it assesses the efficiency of the management model and its potential for continuous improvement and progress [9] , enabling trainees to identify errors and areas for improvement. Active analysis of performance empowers trainees to avoid repeating mistakes and uncover concealed errors. Through the PDCA cycle, trainees are encouraged to reflect on their learning challenges, evaluate outcomes, compare achieved and expected goals, and develop strategies for enhancement [10]. This systematic approach not only enhances technical proficiency but also instills a mindset of continuous learning and improvement.

In conclusion, our study highlights the critical role of the PDCA cycle in enhancing team competencies in challenging airway simulation scenarios. The systematic implementation of PDCA not only improves technical proficiency but also boosts self-efficacy and fosters a culture of perpetual development within healthcare teams. Integrating PDCA into training protocols provides a structured framework for ongoing evaluation, adaptation, and skill enhancement. This systematic approach is essential for optimizing team dynamics and ultimately enhancing patient care outcomes through sustained improvement efforts.

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