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Comparison of the Effectiveness of Marked Suction Tubes vs. Plain Suction Tubes in Pediatric Mechanically Ventilated Patients

Kexin Yang*, Yang Zhang*, Menghui Duan*, Qiuju Liang, Jianfei Zhang, Ping Kong, Mengqi Duan#, Xiangwei Chen#

The Third Affiliated Hospital of Sun Yat-sen University, Guangzhou, China
Email: yangkx5@mail3.sysu.edu.cn

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Abstract

Introduction: Endotracheal suction plays a crucial role in the management of mechanically ventilated patients. This study aims to evaluate the clinical effectiveness and safety of suction tubes with markings in mechanically ventilated pediatric patients. Materials and Methods: A randomized assignment was carried out on a cohort of 52 pediatric patients who underwent mechanical ventilation in the Pediatric Intensive Care Unit at the Third Affiliated Hospital of Sun Yat-sen University, covering the period from January 2022 to December 2022. These patients were divided into two groups: an improved group (n = 26) utilizing marked suction tubes, and a regular group (n = 26) employing conventional suction tubes. The objective of our study was to evaluate the clinical effectiveness of marked suction tubes. Results: The effects of the improved group on the vital signs of children undergoing mechanical ventilation were small and statistically significant compared with the regular group ($p < 0.05$). Additionally, the improved group exhibited a reduced frequency of sputum suction, shorter mechanical ventilation duration, and fewer days of hospitalization in the PICU compared to the regular group during the ventilation period. Notably, the difference in the duration of PICU hospitalization was statistically significant ($p < 0.05$). Moreover, the incidence of adverse reactions in the improved group was notably lower, with statistically significant differences observed in airway mucous membrane damage and irritating cough when compared to the regular group ($p < 0.05$). Conclusion: The utilization of marked suction tubes provides clinical nurses with clear guidance for performing suctioning with ease, efficiency and safety. Consequently, advocating for the widespread implementation of marked suction tubes in clinical practice is a commendable pursuit.

*Kexin Yang, Yang Zhang and Menghui Duan contributed equally to this work.
#Corresponding author.

Keywords

Marked Suction Tubes, Endotracheal Suction, Mechanical Ventilation, Different Depth of Aspiration

1. Introduction

Mechanical ventilation is a crucial intervention in critical care settings within clinical practice. Prospective study from 40 countries in 2010 showed 35% utilization of mechanical ventilation in ICU patients [1]. However, this intervention frequently results in respiratory obstruction of varying degrees among patients due to the introduction of an artificial airway. Consequently, this condition hinders swallowing function, suppresses the cough reflex, and disrupts the normal movement of mucus within the respiratory tract, ultimately leading to the retention of sputum [2] [3]. In the pediatric population, mechanical ventilation inflicts more pronounced lung damage, with estimates indicating that approximately 6% of ventilated children may develop acute respiratory distress syndrome (ARDS), necessitating prolonged ventilation [4].

Endotracheal suctioning is an essential and commonly utilized clinical procedure in mechanically ventilated patients, however, it is invasive and has the potential to cause harm [5]. Observational studies conducted in critically ill children have demonstrated that approximately 25% of cases encounter post-suction complications, including fluctuations in hemodynamics, decreased oxygen saturation, and the development of ventilator-associated pneumonia [6] [7] [8]. Consequently, it is crucial to perform endotracheal suctioning with the highest level of accuracy and precision [9].

The current standard clinical procedure entails a nurse manually manipulating the suction tube during tracheal suctioning, which involves inserting it into the tracheal cannula and applying negative pressure suction while slightly elevating the tube in the presence of resistance. Nevertheless, this technique carries a risk of causing harm to the tracheal carina, a highly delicate region of the trachea with distinct sharp features. The stimulation caused by the suction tube elicits robust airway responses, resulting in repeated frictional irritation and consequently increasing the likelihood of damage, erosion, and bleeding of the airway mucosa [10]. Consequently, the 2010 guidelines of the American Association for Respiratory Care (AARC) advocate for the utilization of superficial suctioning as opposed to deep suctioning [11]. This recommendation is grounded in empirical evidence derived from studies conducted on infants and children. Superficial suctioning, which entails inserting the suction tube no further than the endotracheal tube, serves to reduce the potential for harm to the airway mucosa caused by the frontal suction hole of the tube. By adopting this approach, the probability of mucosal bleeding and irritating cough is minimized, ultimately leading to improved patient comfort. If a scale can be marked on the suction

tube, nurses can more accurately gauge the depth of suction tube insertion during endotracheal suctioning to minimize the risk of damage to the airway mucosa, and thus perform shallow suctioning more effectively.

The sputum suction tubes commonly utilized in clinical practice do not possess an integrated scale. Given the diverse characteristics of patients, encompassing age, gender, height, and developmental variations, including variances in tracheal length, the accurate determination of a safe depth for sputum suctioning becomes a complex task. This complexity presents a significant challenge, particularly for novice nurses, in achieving precise and safe suctioning depths, which may ultimately impact the therapeutic outcome in pediatric patients [12]. In response to this concern, we initiated an improvement endeavor utilizing pre-existing technology, which led to the creation of a marked suction tube that serve as a reminder of the depth at which the suction hose should be inserted into the appropriate endotracheal tube. This paper aims to present our examination of the initial clinical implementation of this pioneering suction tube.

2. Material and Methods

2.1. Setting

A total of 52 patients were included in the study, consisting of 32 (61.5%) males and 20 (38.5%) females, with a mean age of (3.9 ± 2.4) years. These patients were receiving mechanical ventilation in the pediatric intensive care unit of our hospital between January 2022 and December 2022. The underlying etiologies for their condition were as follows: severe pneumonia in 30 cases (57.7%), heart failure in 7 cases (13.5%), central nervous system infection in 6 cases (11.5%), infectious shock in 7 cases (13.5%), and cardiac and respiratory arrest in 2 cases (3.8%). The families of these children provided informed consent, and they were randomly assigned to either the improved group or the regular group.

2.2. Inclusion and Exclusion Criteria

Inclusion criteria were as follows: 1) Age range of 1 month to 14 years; 2) Conformance to the clinical indications for tracheal intubation and mechanical ventilation support; 3) Anticipated mechanical ventilation duration exceeding 24 hours; 4) Maintenance of stable vital signs in children, encompassing both respiratory and circulatory parameters; 5) Obtaining informed consent from the children's family members, with documentation through signed informed consent forms.

Exclusion criteria were as follows: 1) Age exceeding 14 years; 2) Anticipated mechanical ventilation duration of 24 hours or less; 3) Presence of a critically unstable condition with the potential for imminent deterioration; 4) Refusal of the child's family to participate in the study.

2.3. Measures

2.3.1. Research Methods

A comparative analysis was conducted on patients undergoing mechanical ven-

tilation, before and after the utilization of marked and standard suction tubes. Endotracheal suctioning was performed when any of the following indications were met: 1) Visual observation of secretions in the airway; 2) Audible presence of coarse wet rales during lung auscultation; 3) Evidence of decreased oxygen saturation and/or deterioration in blood gas analysis parameters associated with airway secretions. 4) The ventilator displayed a sawtooth change in the flow-volume loop, after ruling out ventilator line disturbances and fluid accumulation; 5) A decrease in tidal volume linked to airway secretions or an increase in peak inspiratory pressure during volume-controlled mechanical ventilation.

The marked sputum suction tube (Patent No. ZL 201820344931.7) is equipped with a sputum suction hose that incorporates distinct safety and warning marking zones (Figure 1). The safety marking zone, which extends along the wall of the sputum hose, is a continuous green segment measuring 1.5 to 3 cm in length. Its upper end aligns with the end of the sputum hose, matching the length of the corresponding tracheal cannula, and serves as a reminder of the depth of suction of the sputum hose into the corresponding tracheal tube, within which the endotracheal suction maneuver can be safely performed. Adjacent to the safety marking zone is the warning marking area, delineated by sterile red paint on the outer surface of the suction hose, which is 1 - 2.5 cm in length and contrasts with the green safety marking zone color, suggesting that the suctioning operation needs to be carried out with caution in the depth range. Once this zone is exceeded, the tracheal carina may be damaged, which can result in a number of hazards. During the process of sputum suctioning, the suction hose, which is equipped with markings, is connected to the negative pressure source. This hose

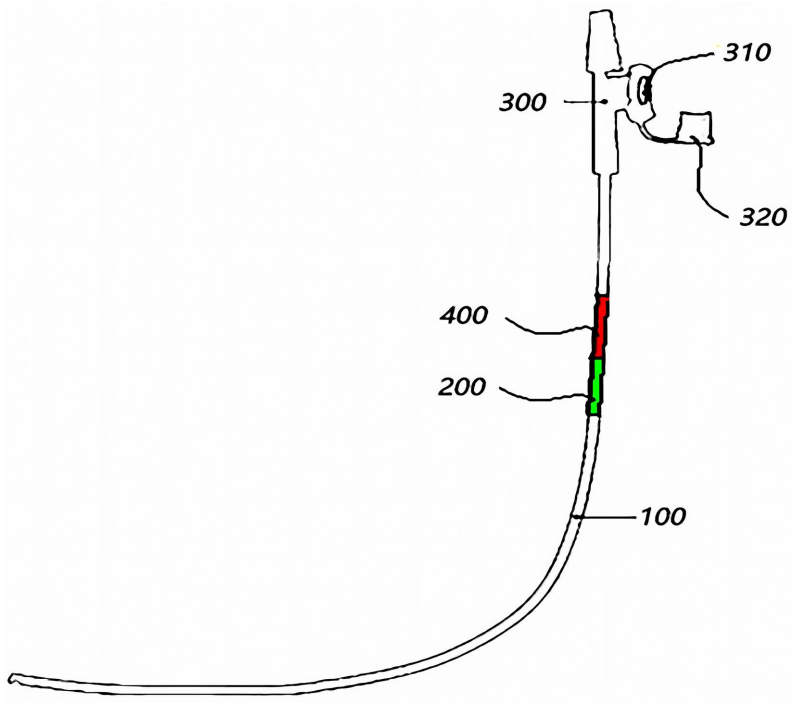

Figure 1. Diagram illustrating the sputum suction tube with markings.

is then inserted into the airway through the tracheal tube, and the suctioning of sputum begins once the green safety marking zone aligns with the tip of the endotracheal tube. In contrast, a conventional sputum suction tube consists solely of the suction hose, which is connected to the negative pressure source and inserted into the tracheal tube for suction. The appropriate depth of insertion is determined by estimating the depth of tracheal intubation.

Both before and after sputum suction, a 30 - 60 second interval of pure oxygen administration was observed. The negative suction pressure was carefully maintained within the range of −80 - 150 mmHg. Initially, oropharyngeal and nasopharyngeal suctioning was performed, followed by airway suctioning. The suction tube was advanced without negative pressure and rotated while being gradually lifted during the suctioning process. Ideally, the entire process, from insertion to withdrawal of the sputum tube, should not exceed 15 seconds.

2.3.2. Observation Indicators

We observed and recorded vital signs 5 minutes before and 10 minutes after sputum aspiration, monitored adverse reactions following sputum aspiration, and conducted an overall assessment of sputum effect upon the patients' discharge from the hospital. Vital signs indicators encompassed heart rate, mean arterial pressure, respiratory rate, and oxygen saturation. Adverse reactions were evaluated in terms of irritating cough, airway mucosal injury, and the incidence of ventilator-associated pneumonia. Evaluation criteria for sputum effect included the frequency of sputum suctioning, duration of mechanical ventilation, and the number of days of hospitalization in the Pediatric Intensive Care Unit (PICU).

2.3.3. Quality Control

All nurses who performed the procedure had undergone extensive professional training and strictly followed the protocol for the "Invasive Mechanical Ventilation Endotracheal Suctioning Technique Operation." Rigorous adherence to hand hygiene practices was observed prior to and following suctioning. Prior to use, the suction tube was adequately lubricated with sterilized water to ensure sufficient suction force and smooth insertion. Simultaneously, two medical professionals, including a doctor and a nurse, were designated as dedicated quality control personnel, responsible for overseeing quality control and the interpretation of various objective indicators. Uniform brands of ventilators, disposable ventilator tubing, and disposable endotracheal tubes were employed for all patients undergoing mechanical ventilation.

2.3.4. Statistical Analysis

The data analysis was conducted using statistical software packages SPSS 25.0 and GraphPad Prism 9.5.1. Descriptive statistics were used to present mean ± standard deviation ($\bar{x} \pm s$) for normally distributed measurement data, while intergroup comparisons were performed using the independent samples t-test. Categorical data were expressed as counts and percentages (%), and between-group

comparisons were conducted using the χ^2 test. Statistical significance was defined as $p < 0.05$.

3. Results

3.1. Comparative Analysis of Baseline Information between the Improved and Regular Groups

Table 1 presents the demographic characteristics of the study participants. The study cohort consisted of 52 mechanically ventilated children, with 26 in the improved group, having a mean age of (3.7 ± 2.4) years, and 26 in the regular group, with a mean age of (4.1 ± 2.5) years. In the improved group, 15 (57.7%) were male, and 11 (42.3%) were female, whereas in the regular group, 17 (65.4%) were male, and 9 (34.6%) were female. Diagnostic distribution in the improved group included 15 (57.7%) cases of severe pneumonia, 4 (15.4%) cases of heart failure, 3 (11.5%) cases of central nervous system infection, 3 (11.5%) cases of infectious shock, and 1 (3.8%) case of cardiac and respiratory arrest. In the regular group, diagnoses encompassed 15 (57.7%) cases of severe pneumonia, 4 (11.5%) cases of heart failure, 4 (11.6%) cases of central nervous system infection, and 4 (11.5%) cases of infectious shock. The general clinical characteristics between the two groups exhibited no statistically significant differences ($P > 0.05$), rendering them comparable.

3.2. Comparison of Vital Signs in the Improved and Regular Groups

Table 2 illustrates the disparity in key physiological parameters. The increase in heart rate between the improved and regular groups was (14.7 ± 2.7) and (18.8 ± 3.6), respectively. The increase in respiration was (2.2 ± 0.9) in the improved group and (2.9 ± 1.1) in the regular group. Furthermore, the decrease in oxygen

Table 1. Baseline of characteristics of study participants.

	Regular group (n = 26)	Improved group (n = 26)	P value*
Age (years)	4.1 ± 2.5	3.7 ± 2.4	0.573
Gender, (n%)			0.569
Male	17 (65.4)	15 (57.7)	
Female	9 (34.6)	11 (42.3)	
Disease, (n%)			0.991
Severe pneumonia	15 (57.7)	15 (57.7)	
Heart failure	3 (11.5)	4 (15.4)	
Central nervous system infection	3 (11.5)	3 (11.5)	
Infectious shock	4 (15.4)	3 (11.5)	
Cardiac and respiratory arrest	1 (3.8)	1 (3.8)	

*Statistically significant ($p < 0.05$).

Table 2. Comparison of vital signs after suction between the two groups.

		Regular group	Improved group	P value*
Heart rate	Pre-suction	100.9 ± 12.1	100.9 ± 9.6	0.980
	Post-suction	119.7 ± 12.2	115.6 ± 9.9	0.196
	Increased level	18.8 ± 3.6	14.7 ± 2.7	0.000
Breathing	Pre-suction	25.0 ± 3.1	25.5 ± 3.3	0.607
	Post-suction	27.9 ± 3.6	27.7 ± 3.4	0.812
	Increased level	2.9 ± 1.1	2.2 ± 0.9	0.017
Oxygen saturation	Pre-suction	91.5 ± 1.4	91.6 ± 0.8	0.806
	Post-suction	88.3 ± 2.2	89.4 ± 1.6	0.054
	Decreased level	3.2 ± 1.4	2.2 ± 1.1	0.009

*Statistically significant ($p < 0.05$).

saturation stood at (3.2 ± 1.4)% in the improved group and (2.2 ± 1.1)% in the regular group. Notably, the comparisons of heart rate, respiration and oxygen saturation between the two groups exhibited statistically significant differences ($p < 0.05$).

3.3. Comparison of Adverse Reactions in the Improved and Regular Groups

In the improved group, 4 patients (15.4%) experienced airway mucosal injury, as opposed to 12 patients (46.2%) in the regular group. Furthermore, 6 patients (23.1%) in the improved group reported irritating cough, compared to 14 patients (53.8%) in the regular group. Notably, no patients (0.0%) in the improved group developed ventilator-associated pneumonia (VAP), while 2 patients (7.7%) in the regular group did. These discrepancies in airway mucosal injury and irritating cough between the two groups were found to be statistically significant ($p < 0.05$). (**Figure 2**)

3.4. Comparison of Sputum Suction Effect between the Improved Group and the Regular Group

The improved group exhibited a reduced frequency of sputum aspiration during mechanical ventilation, a shorter total duration of mechanical ventilation, and fewer days of PICU hospitalization in comparison to the regular group. As depicted in **Table 3**, the mean number of 24-hour sputum aspirations in the improved group was (5.2 ± 0.9) times, while it was (5.0 ± 0.5) times in the regular group. The average total duration of mechanical ventilation for children in the improved group was (38.4 ± 14.2) hours, as opposed to (40.0 ± 14.6) hours in the regular group. Furthermore, the mean duration of hospitalization in the PICU for children in the improved group was (4.1 ± 0.7) days, compared to (4.5 ± 0.6) days in the regular group. The distinction in PICU stay was notably significant between the two groups ($p < 0.05$).

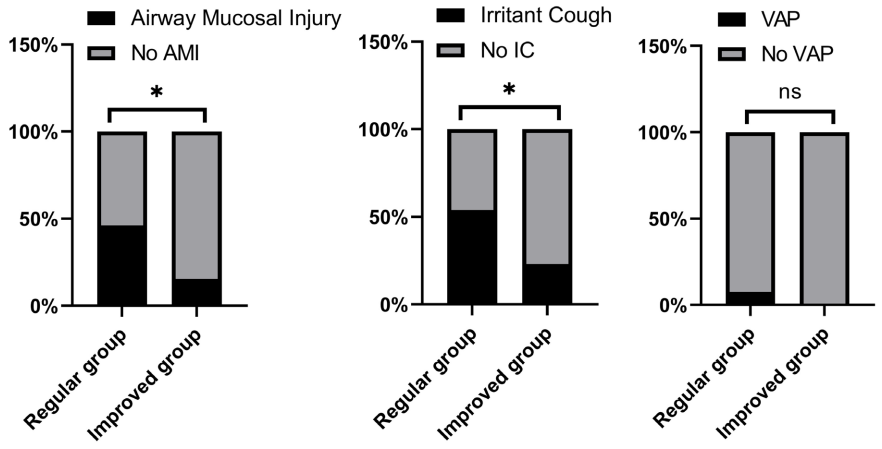

Figure 2. Comparison of adverse reactions in the improved and regular groups. Note: Statistical abbreviations: N.S. = not significant ($p > 0.05$); * = significant ($0.001 < p < 0.05$).

Table 3. Comparison of the effectiveness of sputum aspiration between the two groups.

	Regular group	Improved group	p value*
Frequency of 24-hour sputum suction	5.0 ± 0.5	5.2 ± 0.9	0.362
Total time on mechanical ventilation	40.0 ± 14.6	38.4 ± 14.2	0.687
PICU hospitalization days	4.5 ± 0.6	4.1 ± 0.7	0.047

*Statistically significant ($p < 0.05$).

4. Discussion

Endotracheal suctioning is a crucial component of airway management for patients receiving mechanical ventilation [13]. Despite its widespread use and acknowledged advantages, such as maintaining airway patency, timely removal of airway secretions, prevention of airway obstruction, and its critical role in preventing pulmonary complications, this procedure can be classified into two primary categories: shallow and deep suctioning [14]. The differentiation between these categories is determined by the extent of insertion of the suction tube [15]. The procedure of shallow sputum aspiration involves the insertion of the suction tube to a predetermined depth, typically equivalent to the depth of tracheal intubation plus the length of the connecting tip. Conversely, deep sputum aspiration entails inserting the suction tube into the tracheal tube until resistance is encountered, and subsequently withdrawing it by 1 cm to initiate negative-pressure suction [16]. Improper endotracheal suctioning has the potential to result in various negative consequences, including injury to the airway mucosa, fluctuations in hemodynamics, and an increase in intracranial pressure [17]. These risks are especially relevant in pediatric patients, particularly those with limited tolerance, as endotracheal suctioning can have a significant impact on mean arterial pressure, oxygen saturation, and oxygenation indices [18] [19]. Consequently, ensuring the safe and effective implementation of endotracheal suctioning in mechanically ventilated children poses a pressing challenge. In light of

this challenge, we have developed a sputum suction tube that incorporates a marking system inspired by the "traffic light" concept. The primary idea behind traffic signal systems, which are a crucial component in managing road and urban traffic, is to provide vehicles clear instructions on when to stop and when to move forward by using various colored lights. All vehicles must stop and cannot move forward when the traffic signal light is red, which is a signal of danger. However, when the light is green, which is an indication of safe passage, all vehicles can move forward [20]. This novel solution has been implemented and effectively utilized within the PICU.

In this study, the improved group utilized sputum suction tubes with integrated markings for endotracheal suctioning, while the regular group employed conventional sputum suction tubes, with the depth of insertion estimated based on tracheal intubation. The findings revealed that, in terms of vital signs, patients in the improved group exhibited minimal fluctuations in key parameters, including heart rate, respiration and oxygen saturation, before and after sputum suctioning. The findings of this study indicate that the use of sputum suction tubes equipped with markings for endotracheal suctioning may enhance the maintenance of respiratory cycle stability in pediatric patients and facilitate the smooth implementation of mechanical ventilation.

Moreover, the clinical validation of utilizing labeled suction tubes has been conducted to assess their safety. When compared to the conventional use of standard suction tubes for endotracheal suctioning, the utilization of labeled suction tubes has exhibited a noteworthy reduction in the occurrence of airway mucosal injury, irritating cough, and cases of ventilator-associated pneumonia. Furthermore, marked suction tubes have shown considerable promise in improving the quality of nursing care. This study provides evidence that the modified group was able to decrease the frequency of suctioning, shorten the duration of mechanical ventilation, and significantly reduce the length of hospital stay in the PICU. These findings highlight the effectiveness of labeled suction tubes in alleviating clinical care burdens and expediting the recovery process.

5. Conclusion

When managing pediatric patients having endotracheal intubation in the intensive care unit, the use of marked suction tubes has many benefits, particularly in mitigating the occurrence of adverse reactions linked to mechanical ventilation. This approach demonstrates the potential to improve the effectiveness of sputum suctioning, reduce the duration of mechanical ventilation, and facilitate overall recovery. Clinical nurses can further enhance airway protection for critically unwell infants and children by using this strategy. As a result, we support the general adoption of this method in pediatric intensive care units at all hospital levels. Furthermore, future research could be expanded to adult intensive care unit patients to determine whether marked suction tubes are equally helpful, enabling the creation of tailored treatment options.

Conflicts of Interest

The authors declared no conflicts of interest.

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