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Article

Effectiveness of Fiberoptic Bronchoscopy-Assisted Extubation in Infants After Congenital Heart Surgery

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Abstract

Objective: This study aimed to evaluate the effectiveness of flexible bronchoscopy (FB)-assisted extubation compared to conventional extubation strategies in managing extubation failure (EF) in infants after congenital heart disease (CHD) surgery. **Methods**: A historical control study included 95 infants who underwent CHD surgery between May 2021 and May 2023. Patients were divided into two groups based on the postoperative extubation management strategy: the conventional weaning (CW) group (n=45) received management without FB assistance to prevent EF, and the FB group (n = 50), where FB was actively utilized to facilitate extubation. **Results**: The FB group demonstrated a significantly lower reintubation rate than the CW group (4% vs. 18%, p = 0.043). Additionally, the FB group exhibited shorter durations of mechanical ventilation, noninvasive ventilation (NIV), and hospital stays ($p < 0.05$). No significant differences between groups in EF rates (14% vs. 18%, p = 0.779) or extubation-related complications were observed. Findings relating to FB-assisted extubation identified subglottic stenosis, airway granulation, and mucus plug obstruction as common contributors to EF, facilitating targeted interventions. **Conclusions**: FB-assisted extubation may reduce reintubation rates and hospital stays in infants after CHD surgery without increasing complication risks; however, further studies are needed to validate these findings.

Keywords

fiberoptic bronchoscopy; extubation failure; congenital heart disease; infants; airway management; postoperative outcomes

Introduction

With advances in cardiac surgical techniques and perioperative management, an increasing number of infants with congenital heart disease (CHD) are able to undergo successful surgical repair during infancy, thus resulting in favorable outcomes. However, the success of postoperative intubation is an important factor in the perioperative care, and extubation failure (EF) is one of the greatest challenges regarding this scenario. The reported EF after congenital heart surgery (CHS) rates in infants vary from 2.3% to 22%, meaning increased risk of reintubation, higher postoperative complications, prolonged hospital stays, and ultimately soaring healthcare costs [1–4].

Fiberoptic bronchoscopy (FB) is a valuable tool in airway management, whereby it provides not only a direct view of the anatomy of the airway but also pathological changes; moreover, this tool allows for the drainage of secretions to be, performed and an elucidation of the reasons underlying EF [5,6]. In infants following CHS, FB is especially powerful in ruling out tracheobronchial anomalies such as subglottic stenosis, tracheomalacia, and secretion-induced airway obstruction, which are the factors responsible for EF [7,8]. Despite its potential advantages, studies investigating the role of FB in extubation management in infants are limited, and its clinical benefits remain unclear.

Existing literature predominantly focuses on adult or older pediatric patients, with relatively few studies targeting the unique anatomical and physiological characteristics of infants. The narrower airways and more compliant cartilage typical of infants may lead to different pathogenesis and management of EF compared to older populations. This study aims to evaluate the clinical impact of FB-assisted extubation compared with conventional extubation strategies in infants after CHS. Moreover, we sought to assess the role of FB in reducing EF rates, minimizing the risk of reintubation, and improving postoperative outcomes.

Materials and Methods

Study Population

This historical control study was designed to evaluate the effectiveness of FB in managing EF in infants following CHS. Data were collected from the electronic medical records system of our institution from May 2021 to May 2023. The study population consisted of infants diagnosed with CHD who underwent surgical repair and whose recovery was monitored in a cardiac intensive care unit (CICU). Patients were divided into two groups according to EF and the necessity for reintubation. The conventional weaning (CW) group included patients who were treated between May 2021 and May 2022, for whom FB equipment and techniques were not available in the CICU. In this group, extubation was managed by invasive ventilation followed by noninvasive ventilation noninvasive ventilation (NIV), and EF occurred without the use of FB. The FB group consisted of patients treated between June 2022 and May 2023, during which FB equipment and techniques were introduced. In both groups, the similar weaning strategies involved the application of invasive ventilation followed by NIV-but with the use of FB in those patients with EF. No other factors influenced the classification of the patients into the groups other than the time factor.

The inclusion criteria for this study consisted of infants diagnosed with CHD who underwent surgical repair and experienced EF in the CICU, provided that they were not requiring any respiratory support other than nasal continuous positive airway pressure (NCPAP) following extubation. The exclusion criteria included being extubated in the operating room; undergoing palliative surgery for CHD; exhibiting nasal bleeding, nasal trauma, or severe coagulation disorders; and having incomplete or missing data. Patients who required other types of respiratory support (such as normobaric supplemental oxygen or high-flow oxygen) were excluded from the study to ensure the consistency and comparability of the study population. Extubation Criteria and EF Definition

The indications for extubation were as follows: hemodynamic stability, fraction of inspired oxygen (FiO_2) $\leq$40%, peak inspiratory pressure (PIP) $\leq$18 cmH_2O, positive end-expiratory pressure (PEEP) 2–4 cmH_2O, and arterial blood gas (ABG) results showing partial pressure of carbon dioxide ($PaCO_2$) <50 mmHg, partial pressure of oxygen (PaO_2) >70 mmHg, pH >7.30, and lactate <2.0 mmol/L. Before extubation, the attending physician in the CICU and the bedside nurse assessed whether the chest wall movement and auxiliary muscle use of the patients were sufficient.

For NIV, NCPAP was routinely applied after extubation. Using silicone nasal prongs and the Infant Flow System (EME, Brighton, UK), the initial PEEP was set to 3 cmH_2O (adjustable range: 3–6 cmH_2O) and the FiO_2 range was 0.21 to 0.60. To prevent gastric distension and vomiting, a nasogastric tube was placed in all of the patients before initiating NIV.

EF was defined as the need for reintubation within 72 hours of the first planned extubation. Reintubation was based on the following criteria, determined by the attending physician and the CICU nursing team: respiratory dysfunction (e.g., hypoxemia or hypercapnia), hemodynamic instability, altered mental status (e.g., lethargy), or weak, shallow breathing with severe respiratory distress despite maximal NIV support or FB intervention.

Fiberoptic Bronchoscopy Protocol

Between June 2022 and May 2023, FB was performed on infants with EF based on the joint decision of the attending physician and the CICU nursing team. Gastric contents were aspirated via a nasogastric tube before FB. FB was performed under appropriate sedation and monitoring in the CICU. Continuous monitoring of pulse oximetry (SpO_2), heart rate, and mean blood pressure were continuously monitored via a Bene Vision N19 patient monitor (Mindray Medical International, Shenzhen, China).

The sedation regimen included midazolam (0.1–0.3 mg/kg, total dose $\leq$10 mg) and/or propofol (1–1.5 mg/kg). The airway was topically anesthetized with 1% lidocaine spray (total dose <7 mg/kg). FB was performed using a 2.8 mm Seeshem video bronchoscope (model BR 1249, Zhuhai, China) inserted transorally to assess the airway. During the procedure, secretions were cleared and airway patency was restored to allow for successful extubation.

When necessary, airway lesions could be treated with forceps removal of granulation tissue, balloon dilatation, or inhaled medications (e.g., budesonide). To optimize oxygenation and minimize hypoxemia during biopsy, NCPAP support is provided throughout the procedure [9]. Vital signs were continuously monitored to control for potential complications.

Outcome Measures and Definitions

The demographic data, medical history, and FB results of the patients were thoroughly reviewed from the electronic medical records to ensure data completeness and accuracy. The following information was collected with respect to baseline data before extubation: duration of mechanical ventilation, PaO_2/FiO_2 ratio, left ventricular ejection fraction, preoperative respiratory failure, pulmonary hypertension, postoperative use of inhaled nitric oxide, surfactant therapy, high-frequency oscillatory ventilation and surgical parameters.

The primary outcome of the study was the number of patients requiring reintubation, while secondary outcomes included extubation failure rate, total duration of invasive

Table 1. Baseline characteristics of included infants[a,b].

Characteristics	CW (n = 45)	FB (n = 50)
Sex (Male/Female)	24/21	23/27
Age at surgery, months	3.5 (1.1, 5.2)	7 (1.5, 5.0)
Weight at surgery, kg	6.3 (3.9, 7.5)	6.1 (4.0, 7.2)
Pulmonary hypertension, n (%)	27	31
Preoperative respiratory failure, n (%)	15	17
MV before surgery, n (%)	8	10
RACHS-1 category		
1	3	5
2	12	13
3	14	16
4	14	13
5	2	3
CPB time, minutes	125 (92–171)	115 (86–166)
Aortic cross-clamp time, minutes	65 (50–96)	70 (55–93)
Delayed sternal closure, n (%)	9	10
Postoperative inhaled nitric oxide, n (%)	6	8
Postoperative ARDS, n (%)	6	9
HFOV after surgery, n (%)	3	5
Left ventricle ejection fraction at extubation, %	55 (48–63)	53 (47–65)
Vasoactive-inotropic score at extubation	7.0 (5–8.0)	7.0 (5.5–8.5)
Duration of MV before extubation, d	2.0 (1.5–5.0)	2.0 (1.5–4.5)

Abbreviations: CW, conventional weaning; FB, fiberoptic bronchoscopy; MV, mechanical ventilation; RACHS, risk adjustment for congenital heart surgery; CPB, cardiopulmonary bypass; ARDS, acute respiratory distress syndrome; HFOV, high frequency oscillatory ventilation; d, day.

[a] There was no significant difference in the baseline characteristics between the two groups of infants.

[b] Data reported as number and percentage, mean ± standard deviation, or median and interquartile range.

ventilation, duration of NIV, total duration of oxygen therapy, ICU length of stay, ICU readmission rate, total length of hospital stay, and FB examination results. Adverse events, including complications after extubation such as hypoxemia, hypercapnia, pneumothorax, hypotension, arrhythmia, or cardiopulmonary arrest, were recorded. Discharge outcomes, including in-hospital mortality and oxygen dependency at discharge, were also assessed. In addition, the vasoactive-inotropic score (VIS) was calculated as follows: VIS = dopamine dose (μg/kg/min) + dobutamine dose (μg/kg/min) + 100 × epinephrine dose (μg/kg/min) + 10 × milrinone dose (μg/kg/min) + 10,000 × vasopressin dose (unit/kg/min) + 100 × norepinephrine dose (μg/kg/min) [10].

Statistical Analysis

Statistical analysis was performed using SPSS software (version 25.0; IBM SPSS, Inc., Chicago, IL, USA). Baseline characteristics were summarized using descriptive statistics. Continuous variables are expressed as the means ± standard deviations (SDs), and categorical variables are expressed as percentages. Means were compared via Student's *t* test, whereas Fisher's exact test was applied to the categorical data. The Mann-Whitney U test was used to analyze nonnormally distributed data. A two-sided p value $<$ 0.05 was considered to be statistically significant.

Results

Baseline Characteristics

This study screened 98 children who underwent CHS at Fujian Children's Hospital from May 2021 to May 2023. After excluding patients who did not meet the inclusion criteria, 95 patients were included in the final analysis, including 45 patients in the CW group and 50 patients in the FB group.

The baseline characteristics of the patients are summarized in Table 1. There were no significant differences between the CW group and the FB group in gender, age at the time of surgery, body weight, severity of preoperative pulmonary disease, proportion of patients requiring preoperative mechanical ventilation, risk adjustment for congenital heart surgery (RACHS-1) score classification, or surgical parameters (such as cardiopulmonary bypass time and aortic cross-clamp time) ($p > 0.05$).

Table 2. Primary and secondary outcomes.

Variable	CW (n = 45)	FB (n = 50)	*p* value
Reintubation, n (%)	8 (18)	2 (4)	0.043
Extubation failure, %	16	14	0.479
Duration of total mechanical ventilation, d	5 (4, 10)	3 (2, 6)	<0.001
Duration of total non-invasive ventilation, d	4 (3, 8)	2 (1, 5)	<0.001
Duration of total respiratory and/or oxygen supports, d	10 (8, 19)	6 (5, 13)	<0.001
ICU length of stay, d	11 (8, 22)	7 (6, 15)	0.002
Total length of hospitalization, d	21 (15, 28)	17 (14, 23)	0.008
Oxygen therapy at discharge, n	3	1	0.342
Mortality, n	1	0	/

Abbreviations: ICU, intensive care unit.

Table 3. Causes of failed extubation[a].

Variable	CW (n = 45)	FB (n = 50)	*p* value
Hypoxia	15	18	0.785
Hypercapnia	27	28	0.693
Hypotension	5	9	0.344
Pneumothorax	4	3	0.704
Excessive secretion	4	6	0.744
Atelectasis	3	7	0.324
Arrhythmia	3	2	0.665
Diaphragmatic paralysis	1	2	1.000

[a] Data reported as number.

Table 4. Bronchoscopy findings for the FB group.

Variables	FB (n = 50)
Subglottic stenosis	22
Airway granulation	18
Sputum plug blockage	16
Laryngomalacia	10
Tracheomalacia	9
Tracheobronchial stenosis	3
Vocal cord paralysis	2
Laryngeal cleft	2

Primary and Secondary Outcomes

The reintubation rate was significantly lower in the FB group than in the CW group (4% vs. 18%, respectively; $p = 0.043$). However, there was no significant difference observed in EF rates between the two groups (14% vs. 18%, $p = 0.779$). Durations of total mechanical ventilation, NIV, and total respiratory support/oxygen therapy times were significantly shorter in the FB group compared with the CW group ($p < 0.001$). Furthermore, the ICU length of stay and total length of stay were shorter in the FB group compared with the CW group ($p = 0.002$ and $p = 0.008$, respectively). The detailed data are provided in Table 2.

Causes of Extubation Failure

The primary causes of EF included hypoxemia, hypercapnia, hypotension, pneumothorax, excessive secretions, atelectasis, and arrhythmia, among other causes. There was no significant difference observed between the CW group and the FB group with respect to causes of EF ($p > 0.05$). The detailed data are presented in Table 3.

Fiberoptic Bronchoscopy Findings and Complications

In the FB group, FB identified 22 cases of subglottic stenosis (Fig. 1), 18 cases of airway granulation tissue (Fig. 2), 16 cases of mucus plug obstruction, 10 cases of laryngomalacia, 9 cases of tracheomalacia, 3 cases of tracheobronchial stenosis, 2 cases of vocal cord paralysis, and 2 cases of laryngeal cleft (Table 4).

During the FB procedure, 5 patients (10%) developed transient hypoxemia ($80\% < TcSaO_2 < 90\%$), which reversed after transient discontinuation of the procedure and increase in the fraction of inspired oxygen via NIV. There were no severe complications like significant airway bleeding, pneumothorax, bradycardia, cardiopulmonary arrest, or death related to the procedures.

Discussion

EF remains a significant challenge in the postoperative management of infants with CHD, as it is strongly associated with higher reintubation rates and adverse outcomes [11–13]. The present study, therefore, retrospectively evaluated the efficacy of FB in extubation management after CHS using a historical control design. The results showed that FB significantly reduced the reintubation rate, shortened the duration of mechanical ventilation and hospital stay without increasing extubation-related complications.

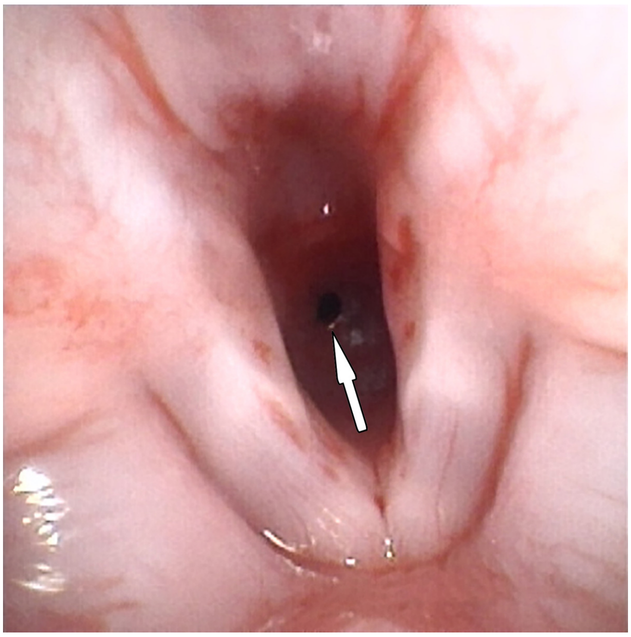

Fig. 1. The arrow points to subglottic stenosis.

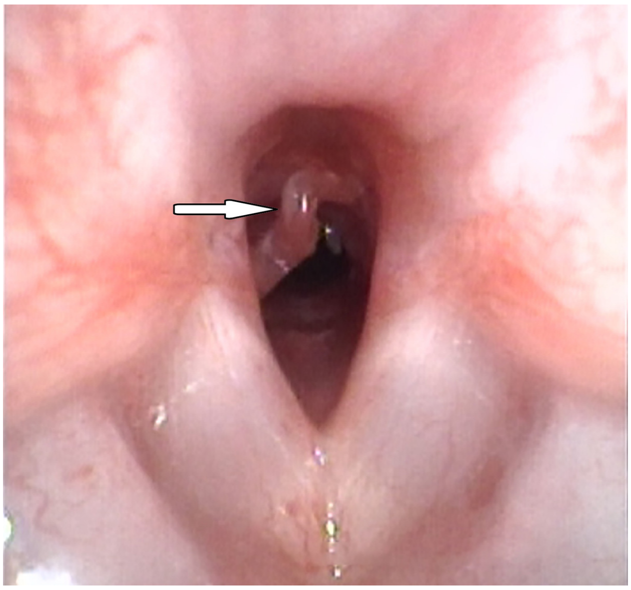

Fig. 2. The arrow points to the subglottic granulation tissue.

These findings provide new evidence for extubation management of infants after CHS and suggest new methods for optimizing extubation strategies.

Our study showed that the reintubation rate was significantly lower in the FB group compared with the CW group (4% vs. 18%, respectively; $p = 0.043$), although there was no statistically significant difference in EF rates between the two groups (14% vs. 18%, $p = 0.779$). While FB does not appear to directly reduce EF rates, it plays a crucial role in preventing reintubation by enabling targeted interventions through the identification and management of airway abnormalities. The decrease in reintubation rates is likely due to FB's ability to identify airway abnormalities, such as subglottic stenosis, mucus plug obstruction, and granulation tissue, enabling targeted interventions like secretion clearance and airway dilation to restore patency and reduce reintubation risks. FB also facilitates individualized extubation management, addressing specific airway abnormalities to optimize outcomes. Other research has indicated that the major causes of EF include abnormalities of the airways and obstruction caused by secretion, which are delineated by FB and are cost-effective [14,15]. Moreover, FB provides secretion clearance and communicates interventional procedures for airway patency when treating obstructive disease, thus further emphasizing its importance in attempting to avoid postextubation airway-related complications.

Compared with the CW group, the FB group exhibited significantly shorter durations of total mechanical ventilation, NIV, and hospital stays ($p < 0.05$). These findings are consistent with the role and effects of FB in the early identification of airway disorders, a reduced rate of reintubation, and a decreased need for prolonged mechanical ventilation. Previous reports have shown that prolonged mechanical ventilation increases the risk of pulmonary infections and other respiratory complications [16–18]. The findings of this research would suggest that feedback mechanisms may indirectly enhance respiratory outcomes and accelerate overall recovery by way of optimizing extubation strategies.

There were no significant differences in extubation-related complications between both groups, such as hypoxemia, hypotension, pneumothorax, and arrhythmias. This is consistent with previous studies showing that FB is a safe and precious diagnostic tool for CHD patients and could guide the therapeutic interventions for pediatric cardiac cases [7,19]. Although some studies have expressed concern over the possible adverse effects of foreign bodies, such as hypoxic events, injury to the airway, or physiological stress responses [20], this case series demonstrated a 10% incidence of transient hypoxemia during the process in 5 patients. Although these effects were skillfully managed and the symptoms were quickly improved, their potential overall impact on treatment outcomes does need to be considered. The current study adhered to appropriate sedation and anesthesia protocols, but no serious adverse events were reported, such as major airway hemorrhage, pneumothorax, bradycardia, cardiopulmonary arrest, or death. However, the occurrence of transient hypoxemia underscores the need for proactive management strategies, including optimal pre-procedure oxygenation, continuous SpO_2 monitoring, and timely interventions to prevent hypoxic events during FB procedures. This would ensure better safety for the patients and emphasize the need for future research in order to prevent hypoxic events during FB procedures.

The findings from the FB examinations that were performed in this study revealed that the most frequent airway abnormalities in the FB group were subglottic stenosis (44%), airway granulation tissue (36%), and mucus plug obstruction (32%). These factors may be major contributors to extubation failure. Previous studies have shown that these kinds of airway abnormalities are highly prevalent in infants after CHS [6,7,21]. Early detection and intervention, with the help of feedback mechanisms, can significantly mitigate the clinical implications of these anomalies and provide a basis for designing individualized extubation strategies.

This is the first study that has systemically evaluated the role of FB in extubation management after CHS in infants, providing multidimensional clinical data on outcomes such as reintubation rates and hospital stays. Nevertheless, this study has a few limitations. First, as a single-center study, the results may be influenced by institutional practices and patient characteristics. Second, the historical control design introduces potential time trend and selection biases, which could affect the generalizability and interpretation of our findings. The non-contemporaneous nature of the study design is a significant limitation, as it may introduce confounding factors related to temporal changes in clinical practice or patient characteristics. Although consistent protocols and comparable baseline characteristics minimized these biases, they cannot be fully excluded. Future prospective randomized trials are essential to validate our findings and mitigate the potential biases introduced by consecutive study periods. Moreover, synthesis of FB findings with other imaging modalities and molecular biomarkers may unravel new insights into improving airway management after extubation.

Conclusions

This study demonstrated that FB-assisted extubation reduced the reintubation rate, ventilation time, and length of hospital stay without increasing complications. Based on the timely recognition and management of airway abnormalities, fiberoptic bronchoscopic extubation provides an effective tool for the development of tailored extubation strategies and demonstrates great clinical utility in improving extubation handling in infants undergoing CHS. Future multicenter randomized controlled trials are needed to validate these results and establish FB-assisted extubation as a standard clinical practice in the postoperative airway management of infants undergoing CHS.

Availability of Data and Materials

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author Contributions

JJL and YRZ conceived the idea; YRZ conducted the analyses; YRZ and SHL provided the data; all authors contributed to the writing and revisions. All authors have participated sufficiently in the work. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript. All authors agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Ethics Approval and Consent to Participate

The study was carried out in accordance with the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of Fujian Children's Hospital (Protocol No. 2022ETKLR12044). As a retrospective study, the ethics committee waived the requirement for written informed consent.

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Conflict of Interest

The authors declare no conflict of interest.

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