

Airway Complications of Pediatric Extracorporeal Membrane Oxygenation

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Objectives: Prolonged intubation is a risk factor for the development of laryngotracheal stenosis. Children who undergo extracorporeal membrane oxygenation (ECMO) usually remain intubated for an extended period. It is unclear whether the impaired cardiorespiratory status that necessitated ECMO places these children at a higher risk of laryngotracheal stenosis. This study was performed to assess the incidences of laryngotracheal stenosis and tracheostomy in children who undergo ECMO.

Methods: We identified all patients under 18 years of age who underwent ECMO over a 10-year period concluding July 1, 2009, by use of the extracorporeal life support database of Royal Children's Hospital, Melbourne. All children in this database who underwent either a diagnostic or a therapeutic surgical procedure on the airway were identified.

Results: The 218 patients included in the study had an overall survival rate of 51.4%. A total of 14 patients (6.4%) required a surgical procedure on the airway, and 11 of these (5.0%) needed tracheostomy. Ten of these 14 patients (71.4%) survived; of these, 2 presented with congenital laryngotracheal stenosis, 3 developed clinically significant laryngotracheal stenosis as a likely consequence of ECMO, and 5 required tracheostomy alone for long-term ventilation. The rate of airway stenosis was 2.7% in survivors.

Conclusions: The rate of laryngotracheal stenosis in children who require ECMO is acceptably low.

Key Words: acquired subglottic stenosis, ECMO, extracorporeal membrane oxygenation, laryngeal stenosis, laryngotracheal stenosis, tracheostomy.

INTRODUCTION

Extracorporeal membrane oxygenation (ECMO) was first used in children by Bartlett et al¹ in 1976. The technology was developed as a refinement of the technique of cardiopulmonary bypass. Typically, veno-arterial ECMO involves large-bore cannulation of a central vein and a central artery. Blood with heparin added is passed through a pump, an oxygenator, and a warmer before being returned to the systemic arterial circulation. This provides both oxygenation and perfusion pressure, and therefore supports both pulmonary and cardiac function. Venovenous ECMO returns the oxygenated blood to the right atrium, providing pulmonary support, but still relies on the heart to drive perfusion.

ECMO is considered in children with severe and potentially reversible cardiorespiratory disease in whom there is a high chance of death with conventional treatment measures.² Patients remain intubated while on ECMO to allow pulmonary toilet and alveolar ventilation, and usually remain intubated after cessation of ECMO until they are deemed suf-

ficiently stable for extubation. Endotracheal intubation is the major risk factor for the development of acquired laryngotracheal stenosis; the risk is related to prolonged intubation, the number of intubation attempts and tube changes, and an inadequately sized or poorly secured endotracheal tube. Other factors include long-term tracheostomy and gastroesophageal reflux. A possible relationship between extracorporeal circulation and an increased risk of airway stenosis was theorized in 1997 by Pereira et al,³ who addressed subglottic stenosis in children undergoing cardiac surgery. They stated that mucosal hypoperfusion due to perioperative hypotension, and the use of extracorporeal circulation, which is known to impair gas exchange, may further predispose the airway to injury.

Children treated with ECMO are exposed to multiple factors that may increase their risk of laryngotracheal stenosis. Despite the increasing use of this support method in the pediatric population, the rate of airway complications in children treated with ECMO has not been addressed in the English-lan-

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TABLE 1. PATIENT CHARACTERISTICS

| | Airway Procedure (n = 14) | No Airway Procedure (n = 204) | Entire Cohort (n = 218) |
|--------------------------------|---------------------------------|-------------------------------------|-------------------------------|
| Age* | | | |
| Mean (mo) | 69.5 | 25.8 | 28.6 |
| Median (mo) | 29.4 | 1.9 | 2.0 |
| Range | 1 d to 16.5 y | 1 d to 17.2 y | 1 d to 17.2 y |
| Mean weight* (kg) | 23.5 | 11.1 | 11.9 |
| Duration of ECMO (d) | 8.3 | 6.6 | 6.7 |
| Duration of ventilation (d) | 53.5 | 14.3 | 16.8 |
| Survival rate at discharge | 71.4% | 50% | 51.4% |

*At start of extracorporeal membrane oxygenation (ECMO).

guage medical literature. We therefore reviewed our institution's experience.

METHODS

The intensive care unit of Royal Children's Hospital, Melbourne (RCHM) prospectively collates an extracorporeal life support database according to guidelines from the Extracorporeal Life Support Organization.⁴ After approval from the hospital ethics committee (RCHM reference No. CA29042), this resource was accessed and all patients under 18 years of age who underwent ECMO were identified for the 10-year period concluding July 1, 2009.

Patient characteristics such as age and weight at the commencement of ECMO and the duration of ECMO and ventilator support were recorded. In addition, the primary diagnosis and survival outcomes were noted to demonstrate the spectrum of disease within the cohort and to allow comparison with other reported series of ECMO in children.

The hospital electronic operative coding system was used to identify patients in the cohort who had also undergone a diagnostic or therapeutic surgical procedure on the airway. The medical records of these patients were accessed, and the presence or absence of laryngotracheal stenosis, details of the airway procedure, and the outcome were noted.

RESULTS

A total of 227 children were identified; 9 patients were excluded because of incomplete data, leaving 218 in the study group. Patient characteristics are displayed in Table 1. The median age was 2.0 months and the mean was 28.6 months (range, 1 day to 17.2 years), indicating that patients in the first 6 months of life dominated the population studied. The mean duration of ECMO was 6.7 days (range, 1.3 hours to 72.8 days), and the mean duration of ventilation was 16.8 days (range, 0.24 hours to 149.0 days). There

TABLE 2. DIAGNOSIS-SPECIFIC SURVIVAL RATES AT DISCHARGE

| Primary Diagnosis | Airway Procedure (n = 14) | No Airway Procedure (n = 204) | Entire Cohort (n = 218) | Survival Rate |
|---------------------------|---------------------------------|-------------------------------------|-------------------------------|------------------|
| Recent cardiac surgery | 5 | 109 | 114 | 47.4% |
| Sepsis | 3 | 33 | 36 | 52.7% |
| Other | 2 | 24 | 26 | 42.3% |
| Cardiomyopathy | 1 | 9 | 10 | 40.0% |
| Meconium aspiration | | 7 | 7 | 85.7% |
| Bacterial pneumonia | | 6 | 6 | 83.0% |
| Diaphragmatic hernia | | 5 | 5 | 60.0% |
| Viral pneumonia | 2 | 2 | 4 | 75.0% |
| Myocarditis | 1 | 3 | 4 | 100% |
| PPHN or PFC | | 3 | 3 | 33.0% |
| RDS or HMD | | 1 | 1 | 100% |
| Pneumocystis pneumonia | | 1 | 1 | 100% |
| Aspiration | | 1 | 1 | 0% |

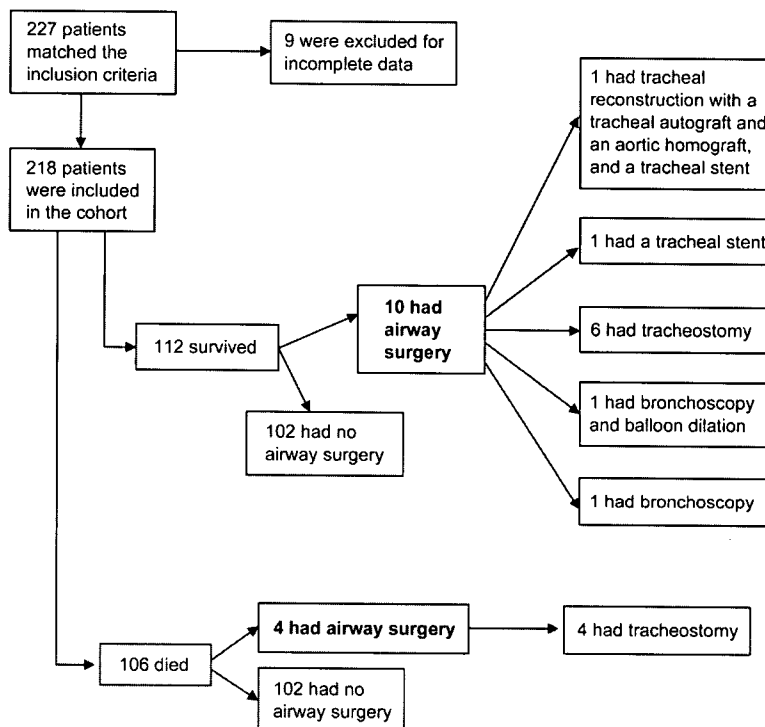
PPHN — persistent pulmonary hypertension of newborn; PFC — persistent fetal circulation; RDS — respiratory distress syndrome; HMD — hyaline membrane disease.

were 112 patients (51.4%) who survived to discharge. The data regarding diagnosis-specific survival at discharge are shown in Table 2.

The patient outcomes are summarized in the Figure. We identified 14 patients who underwent a diagnostic and/or therapeutic surgical procedure on the airway. The median age of these patients was 29.4 months and the mean was 69.5 months (range, 1 day to 16.5 years). The mean duration of ECMO was 8.25 days (range, 2.3 to 15.2 days), and the mean duration of ventilation was 53.5 days (range, 4.2 to 137.8 days). Ten of the 14 patients survived. The 4 patients who died had undergone heart surgery; they all underwent tracheostomy for prolonged respiratory support and died of non-airway-related causes with their tracheostomy in situ.

Details of the 10 patients who survived ECMO and also underwent a surgical airway procedure are shown in Table 3. Congenital laryngotracheal stenosis was the primary diagnosis precipitating admission in 2 of these children. The first had tracheal stenosis with an associated pulmonary artery sling and underwent thoracotomy and tracheal reconstruction using a tracheal autograft and aortic homograft. This required subsequent revision and eventual stent insertion. The patient also developed glottal and tracheal granulation and an anterior glottal web. The second patient with congenital tracheal stenosis was managed with tracheostomy and tracheal and right bron-

Flow diagram of patient outcomes.



chial stenting. His family moved out of the state after discharge, and he was lost to further follow-up.

Three of the 112 survivors (2.7%) developed stenotic lesions, probably as a complication of ECMO

and the associated period of endotracheal intubation. One patient who required ECMO for sepsis was extubated in the operating room after a previous failed attempt in the intensive care unit; bronchoscopy revealed minor subglottic stenosis that did

TABLE 3. CLINICAL DETAILS OF SURVIVORS WHO UNDERWENT AIRWAY SURGERY

| Primary Diagnosis | Tracheostomy, Time to Decannulation | Procedure | Complications |
|---|-------------------------------------|--|--|
| Preexisting laryngotracheal stenosis (n = 2) | | | |
| Congenital tracheal stenosis with pulmonary artery sling | No | Open tracheal reconstruction; tracheal autograft; aortic homograft; tracheal stent | Anterior glottal web; vocal fold and tracheal granulation |
| Congenital tracheal stenosis | Yes, unknown | Tracheostomy; tracheal and right bronchial stent | Lost to follow-up (moved out of state after discharge) |
| Laryngotracheal stenosis secondary to ECMO (n = 3) | | | |
| Sepsis | No | Extubation in operating theater | Minor subglottic stenosis; managed with observation alone |
| Sepsis | Yes, 30 days | Tracheostomy | 40% subglottic stenosis; managed with observation alone |
| Viral pneumonia | No | Bronchoscopy, balloon dilation x3 | Stable 50% tracheal stenosis |
| Nonstenotic complications (n = 5) | | | |
| Myocarditis | Yes, 85 days | Tracheostomy; closure of fistula | Tracheocutaneous fistula |
| Congenital cardiac lesion | Yes, 425 days | Tracheostomy; closure of fistula | Tracheocutaneous fistula; tracheobronchomalacia |
| Viral pneumonia | Yes, 24 days | Tracheostomy | Stomal granulation |
| Sepsis | Yes, 117 days | Tracheostomy | Accidental decannulation |
| Cardiomyopathy | Yes, 62 days | Tracheostomy | Left main bronchus compression from cardiac transplant size mismatch; managed conservatively |

not require further management apart from clinical surveillance. The second patient had an underlying diagnosis of sepsis and required tracheostomy for prolonged support; bronchoscopy revealed a 40% subglottic stenosis. The patient was successfully decannulated on day 30 and only required further clinical surveillance. The third patient was admitted with viral pneumonia; bronchoscopy revealed a 60% tracheal stenosis after extubation. The patient was treated with endoscopic balloon dilation and currently has a stable 50% stenosis.

A 2.7% rate of laryngotracheal stenosis was found in the survivors. Notable complications in other body systems within the 112 survivors included a 39.3% incidence of bleeding at either the cannulation site or the surgical site that required re-exploration, a 37.5% incidence of sepsis, a requirement for dialysis or hemofiltration in 22.3%, and an 11.6% incidence of cerebrovascular accident.

The remaining 5 survivors in the surgical intervention group underwent tracheostomy for prolonged ventilatory support. Their primary diagnoses are listed in Table 3. Four patients were decannulated within 4 months and the other at 14 months. All did, however, suffer complications. These included 2 tracheocutaneous fistulas requiring closure (including 1 with coexisting tracheobronchomalacia), 1 stomal granulation that required debridement, 1 accidental but successful decannulation 117 days after insertion, and 1 extrinsic compression of the left main bronchus from a size-mismatched cardiac transplant that was managed conservatively.

The overall tracheostomy rate in this pediatric ECMO cohort was 5.0% (11 of 218 patients). Of the 112 survivors, 7 had tracheostomies (6.25%); 6 were for prolonged ventilatory support, and 1 was used in combination with tracheal stenting to treat a congenital tracheal stenosis.

DISCUSSION

The English-language literature contains no information regarding the incidence of laryngotracheal stenosis or tracheostomy in children who undergo ECMO. We identified a total of 5 patients with laryngotracheal stenosis. Two of these patients, however, presented with preexisting stenosis as their primary problem, and therefore their airway lesions should not be attributed to the process of ECMO and the accompanying period of endotracheal intubation. A total of 3 survivors (2.7%) were noted to acquire clinically significant laryngotracheal stenosis during their period on ECMO. The rate for development of acquired laryngotracheal stenosis in intubated neonates has been addressed widely within the

medical literature. The review by Walner et al⁵ from 2001 estimates a rate of up to 2.0%. Looking at children, rather than neonates, Wiel et al⁶ published the only age-matched cohort that we can use for direct comparison to our series. They found a 0.9% incidence of laryngotracheal stenosis in 560 intubated children in their pediatric intensive care unit. It is unclear whether any of these children were supported with ECMO.

A total of 11 patients underwent tracheostomy; it was required in 10 for prolonged respiratory support and in 1 to secure the airway in the treatment of tracheal stenosis. Tracheostomy in the neonatal and pediatric population is not undertaken as early and as frequently as has become routine practice in adult intensive care unit management. Neonates in particular are protected from laryngeal injury and subglottic or tracheal stenosis in comparison with older children and adults,⁷ and can therefore remain intubated for extended periods of mechanical ventilation. Neonates often can tolerate endotracheal intubation with little or no sedation, and given their paucity of movement, complications such as accidental extubations, re-intubations, and the increased risk of airway injury that these carry⁸ are all kept to a minimum. Of note, those in our surgical intervention group were considerably older, with a mean age of 69.5 months, compared with 25.8 months in those with no airway procedure. This finding underscores the lower threshold for tracheostomy referral in older children, who do not tolerate prolonged intubation as well.

The diagnosis-specific survival data are shown in Table 2. The higher survival rate of 71.4% in our airway procedure group, compared with 50.0% in the group with no procedure, is somewhat expected, as those being referred for an airway procedure have survived the early, critical phase of their illness. We cannot infer a direct beneficial effect of tracheostomy on the survival rate.

There are limitations to this study. As indicated above, patients were not screened for an airway lesion either before or after their ECMO treatment; therefore, our study only highlights those patients with a symptomatic airway lesion. If all patients were screened with bronchoscopy after ECMO, it is likely that a higher rate of airway lesions would be found. Furthermore, it could also be expected that the rate of laryngotracheal stenosis in nonsurvivors would be equal to or possibly higher than that in survivors. This may further underestimate the true overall stenosis rate for all patients. However, the rate of stenosis in survivors is the more clinically relevant figure. An additional limitation is that we

are unaware whether any patient treated by ECMO at RCHM required subsequent surgical intervention on the airway at another institution. This would be unlikely, given that RCHM is the only institution in the state of Victoria that offers ECMO for children, and given that the provision of pediatric airway surgery is also highly focused at this hospital.

This study offers a guide to intensivists and oto-

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laryngologists as to the likely rates of laryngotracheal stenosis and tracheostomy in the pediatric ECMO population. It also serves to highlight the need for otolaryngologists to maintain involvement in the complex multidisciplinary management of children who require ECMO. Notwithstanding the limits of our study, the rate of laryngotracheal stenosis is low compared with the high rate of complications in other body systems.

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