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Whitney L Quong , Neil Bulstrode , Arun Beeman , Madhavan Ramaswamy , Brannavan Sivakumar , Colin Wallis , Martin J Elliott , Nagarajan Muthialu

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TITLE:

Intrathoracic prosthesis in children in preventing post-pneumonectomy syndrome: Its role in congenital single lung and post-pneumonectomy situations

Whitney L Quong^, Neil Bulstrode^, Arun Beeman*, Madhavan Ramaswamy*, Brannavan Sivakumar^, Colin Wallis#, Martin J Elliott*, Nagarajan Muthialu*
nagarajan.muthialu@gosh.nhs.uk

Departments of *Cardiothoracic Surgery, ^Plastic and Reconstructive Surgery and #Paediatric Pulmonology, Great Ormond Street Hospital, London, United Kingdom

CORRESPONDING AUTHOR. Nagarajan Muthialu FRCSEd, Consultant Cardiothoracic Surgeon, Great Ormond Street Hospital, Great Ormond Street, London WC1N 3JH, United Kingdom, Phone: +442074059200

ABSTRACT

Background: Postpneumopnectomy syndrome (PPS) is an extreme rotation and malposition of mediastinum causing dynamic and symptomatic central airway compression, arising after pneumonectomy or more uncommonly, in congenital single-lung physiology. Affected patients present with severe respiratory compromise. Intrathoracic prosthesis placement is an evolving technique in children that mitigate the effects of thoracic dead space.

Research Question: Assessment of clinical recovery and functional benefit in children undergoing placement of intrathoracic prosthesis following pneumonectomy or in congenital single lung situations.

Study Design and Methods: Retrospective chart review of patients at Great Ormond Street Hospital from 2010 and 2020 was performed of all patients who underwent intrathoracic tissue expander placement. We summarize the outcomes of twenty-four children, including those with both congenital and postpneumonectomy PPS etiology.

Results: 24 children who underwent placement of intrathoracic prosthesis for PPS in the study period with median age of 3.5 months and weight of 5 kg. Single lung etiology was congenital in 15 children (6 agenesis, 9 hypoplasia), and postpneumonectomy in 9 children. In seven patients, there was associated long segment tracheal stenosis. Pre-operative ECMO was required in 2 patients, and pre-operative ventilation was required in 12 patients – all of whom had congenital single lung. Intrathoracic prosthesis placement was concurrent with intracardiac repair in 5 patients. There were no operative deaths, but one early postoperative death related to septicaemia. Median follow up was 75 months with 10 patients on continued respiratory support and 3 on nocturnal support with good quality of life. Two children needed reoperations for replacement of prosthesis.

Conclusion: The use of tissue expanders is within the armamentarium of most plastic surgeons' practice. We also therefore advocate for a collaborative team approach involving Plastic and Cardiothoracic Surgery for surgical treatment of these patients. This multidisciplinary strategy has improved management of this rare and debilitating condition of PPS, thereby offering significant improvements in general progress of these sick children having single lung physiology. Evidence is still lacking on functional outcomes in these children and further work is necessary to prove that this is indeed achievable.

KEYWORDS

Post-pneumonectomy syndrome; Intrathoracic prosthesis; Mediastinum

INTRODUCTION

Postpneumopnectomy syndrome (PPS) is a rare condition of dynamic airway obstruction arising after pneumonectomy or more uncommonly, in congenital single-lung physiology[1]. Without a second lung to occupy the thoracic cavity and stabilize thoracic contents, the heart and mediastinal contents can shift excessively towards the dead space, while the great vessels rotate considerably (Figure 1). Secondarily, the remaining over-distended lung herniates, and the pulmonary artery can compress the distal trachea/main bronchus against the vertebral column or aorta. Consequently, the patient may develop severely symptomatic central airway compromise and dynamic airway obstruction.

Eliminating the thoracic dead space is crucial to maintaining normal anatomy, preventing the malposition of the mediastinal contents, and thereby reducing the risk of abnormal respiratory function. We describe the outcomes of 24 pediatric patients who underwent intrathoracic tissue expander placement for PPS, and our multidisciplinary surgical technique to reverse the associated abnormal physiology.

METHODS

This is a retrospective review of 24 children who underwent placement of intrathoracic prosthesis for PPS in a single institution, between 2010 and 2020. The need for consent and ethics were waived by the Institutional review board for this case notes review. Table 1 shows the demographics , as described. Some of these children were reported originally in our early reports as part of our initial experience[2,3].

Single lung etiology was congenital in 15 children (6 agenesis, 9 hypoplasia), and postpneumonectomy in 9 children. In seven patients, there was associated long segment tracheal stenosis. Pre-operative ECMO was required in 2 patients, and pre-operative ventilation was required in 12 patients – all of whom had congenital single lung. The median age and weight at first airway surgery was 3.5 months, and 5 kg, respectively. Five patients had associated cardiac anomalies, while 7 had non-cardiac anomalies. Prior to prosthesis placement, all patients had undergone pericardiopexy.

Among those 9 children who had undergone pneumonectomy, two of them were for malignant lung pathology (one being mucoepidermoid carcinoma of bronchus extending into branches and another with inflammatory myofibroblastic tumour; both being unable to salvage any part of lung parenchyma) and rest of children with infective pathology of various reasons needing surgery.

Assessment of these children included conventional cross-sectional imaging including computed tomography of chest (CT scan of chest) and airway assessments. These include bronchoscopy and where needed, bronchogram for dynamic assessments. Following these assessments, a multi-disciplinary discussion was conducted to review and decide on the need for placing the intrathoracic prosthesis. This is based on our experience in wider critical airway programme, that helps children born with congenital tracheal stenosis, including those with single lung.

SURGICAL TECHNIQUE

The surgical technique is summarized in Figure 2. The patient, under general anaesthesia, is placed in the lateral position and a horizontal lateral thoracotomy incision is marked from just below and lateral to the angle of the scapula to just below and lateral to the nipple areolar complex to avoid compromising future breast development. Local anaesthetic is infiltrated. A muscle-sparing lateral thoracotomy approach has been developed to preserve the integrity of the latisimus dorsi (LD) and the serratus anterior (SA). After skin incision, skin flaps are raised in the plane of the muscle fascia, exposing the LD and SA. The anterior edge of the LD is identified and muscle belly is dissected and retracted posteriorly. This exposes the posterior edge of the SA which is then dissected and retracted anteriorly exposing the ribs. The 4^{th} or 5^{th} intercostal space is chosen to enter the pleural cavity, and great care is required as the mediastinum has rotated into the pleural cavity at this point. The mediastinum is released and dissected away allowing it to rotate returning to a more normal central anatomical position. Dissection includes freeing up of anterior adhesions between thymus and pericardium to the anterior chest wall. Pericardium is further freed up from the lateral chest wall and at this stage, and assessment is made to remove any remnant of lung or other fatty tissues in the pleural cavity to facilitate effective placement of the prosthesis. All patients undergo pericardiopexy to maintain the repositioning of the mediastinum and its contents depending on the cardiorespiratory parameters and bronchoscopic appearance. Pericardiopexy is done by anchoring the anterolateral aspect of the corresponding pericardial reflection to the bony part of anterior chest wall – this can be either end of corresponding ribs or lateral border of sternum. Appropriate assessment is carried out at this stage to ensure there is no extreme rotation and additional compression of cardiac chambers at this stage. An appropriate intrathoracic drain to facilitate clearance of any residual fluid is positioned. The pre-ordered expander (Nagor prosthesis, GC Aesthetics, Glasgow, United Kingdom), according to preoperative calculations estimating thoracic cavity size, is then prepared and inserted. It is filled gradually with close communication with the anaesthetic team according to the cardiorespiratory parameters. The port passes though the intercostal incision and the ribs are approximated with 0 vicryl sutures.

The undamaged muscle bellies of the SA and LD are allowed to assume their normal position and re-drape in a double-breasted manner. The anterior edge of the LD is tacked to the SA in the normal position using 4-0 vicryl. A pocket is then created inferiorly on the muscle fascia for the expander port which is sewn down to prevent rotation using a 4-0 monocryl. The superficial fascia layer is closed followed by a dermal and subcutaneous suture. The drain is left on free drainage, not active, to reduce the tendency for the mediastinum to rotate back into the cavity. The patients, especially following pneumonectomy typically spend one night in the intensive treatment/care unit for close monitoring. Children born with congenital single lung can stay in intensive care unit for much longer period, due to their need for augmented airway management. The expander is imaged and further expansion can be performed if required.

RESULTS

24 children underwent placement of intrathoracic prosthesis (as seen in table 2). Majority of these (21 out of 24) were on the right side. Out of these, 9 children had undergone pneumonectomy for various reasons, and needed placement of prosthesis as part of their management plan. 3 children had placement of such prosthesis as primary procedure during pneumonectomy and delayed at a second stage in 6 children.

Intrathoracic prosthesis placement was concurrent with intracardiac repair in 5 patients, and further airway interventions (dilatation, tracheostomy) in 7 patients (Table 2).

Four children had redo thoracotomy in our series. Two of them had undergone surgery elsewhere for prosthesis placement, but had collapsed prosthesis with consequent airway-related symptoms. Surgery at our centre included redo thoracotomy, removal of the damaged prosthesis and release of fibrotic processes completely before a new prosthesis is placed.

In the remaining two of the above four, the prosthesis had collapsed for an unknown mechanical issue, needing further replacement via redo thoracotomy. The surgical steps were similar as above, with careful attention to releasing the fibrotic processes, thereby allowing mediastinum to maintain and/or acquire the central position before a new prosthesis is positioned.

There was one death in the early postoperative period. This child presented with unexplained syndrome, long segment tracheal stenosis, congenital single lung and chest wall malformations. With critical airway stenosis, this had undergone tracheostomy with little benefit in neonatal phase initially at the referral centre before arriving at our centre for further management. Our sequentional management included mediastinal stabilisation using placement of prosthesis initially followed by aortopexy for relieving pressure on the stenotic airway before needing a slide tracheoplasty. But following aortopexy and during a long intensive care unit stay, this child acquired severe blood-stream infection and died after 47 days from the day of surgery.

Median follow up for 75 months. Our follow up strategy include both clinical assessment and combined echocardiography and micro-laryngobronchoscopy (MLB). Using these two

modalities help us in evaluating the cardiac chambers and great vessels with echocardiography, especially if there were any pressure effects related to the prosthesis itself. Further, using MLB helps in understanding the position of carina and relationship between the two bronchial origin with relevance to the behaviour of prosthesis.

Postoperatively, 10 patients remained on continued respiratory support, with 3 only on nocturnal support with good quality of life during day. Out of these 10 children, 5 of them had associated tracheal stenosis, with one of this five being on nocturnal support only.

Seventeen patients required at least one reinflation of the prosthesis to allow for growth, while 5 patients required at least two reinflations for optimization of mediastinal positions. This happened with both echocardiography and MLB as a means to guide the level and completeness of inflation.

DISCUSSION

Physiological single lung, whether congenital or post-pneumonectomy, poses a risk of PPS in children. This susceptibility to PPS is greater than that of adults, due to a more supple pediatric mediastinum[2]. Its incidence after pediatric pneumonectomy is 2%[3], but is globally rare nonetheless, as pneumonectomy is a rare procedure in childhood. First preliminarily documented in 1953 with a postmortem analysis, it was described that aortic compression of the trachea could arise secondary to agenesis of the lung[4]. It was not until 1972 though, that the clinical syndrome was named, and its relationship to pneumonectomy inextricably solidified[1]. However, the majority of reports on PPS have neglected to address outcomes of cases arising from a congenital (hypolasia or agenesis) etiology. This series of 24 patients therefore represents a significant advancement in the experience with PPS[3], as we describe a technique that can achieve acceptable outcomes in both acquired, and congenital pediatric single lung physiology.

Patients with PPS may present with progressive dyspnea on exertion and stridor leading to reduced exercise capacity, respiratory failure requiring respiratory support, or tracheomalacia[5]. Esophageal symptoms may also coexist, and include from feeding difficulties, recurrent regurgitation, or aspiration[2,5].

Diagnostic workup should comprise pulmonary function tests, and evaluation of the contralateral lung for any residual disease. Absence of residual disease should alert the clinician to the possibility PPS, and further investigation should involve a CT scan with contrast to delineate the position of the mediastinum. Exercise studies may supplement imaging studies, to define the extent and functional impact of symptoms. Bronchoscopy remains the gold standard diagnostic test to rule out a primary obstructive pathology in the contralateral bronchial tree. Cross sectional imaging, especially CT scan of chest, has traditionally been accepted as a method to evaluate chest cavities, and is helpful in guiding the choice of prosthesis including its correct dimensions.

Management options for PPS include conservative treatment and surgical intervention. Conservative treatment of PPS is often successful in alleviating symptoms, but surgery is

indicated in those patients who fail to achieve sustained improvement. Surgery is often indicated in children who remain on respiratory support, to improve their quality of life[6].

Despite recognition that surgical correction of PPS should aim to restore the mediastinum to its normal anatomic relationships to allow the compromised airway to assume its normal position and patency[7], numerous surgical techniques have been posited, with varying results[1,8-10]. Crush of the phrenic nerve with the intent of raising the diaphragm to derotate the heart[4], aortopexy (suture fixation of the aorta to the sternum)[11], placement of endobronchial stents[12], and tracheal/bronchial resection with re-anatomosis anterior to the aortic arch[8] have all been described for surgical PPS management.

Intrathoracic prosthesis placement is our preferred avenue to achieve improved respiratory support in PPS, by mitigating unanticipated haemodynamic and airway related complications. This strategy of eliminating the dead space has previously been described in adults[13,14], but infrequently in children, and in low case numbers[15,16]. As simple suture repositioning of the mediastinum is associated with recurrence[8], we view elimination of the dead space as essential to surgical success, regardless of the etiology of PPS. Although numerous implant materials have been proposed, including breast implants[17], plastic balls[18], and silastic implants[19], our experience with tissue expanders has been notable.

Tissue expanders offer flexibility, and their use is safe. The prosthesis choice is dependent on various factors[13,20], but generally tissue expanders can be of a fixed-volume, or expandable type. A fixed prosthesis may be useful in adults, but the ability to adjust a prosthesis volume and recenter the mediastinum as a child grows, is a significant benefit of expandable implants. An underfilled, but oversized expander may be an attractive option in the young child, who still has growth potential. Conversely, where there is excessive pressure on the cardiac structures, fluid can be withdrawn from an overfilled expander. Greater conformity and customizability may also be achieved with two smaller expanders placed on top of each other, where expansion rates for each can vary based on the contours of the hemithorax. The issue of leaking expanders however remains, and should be considered in the face of clinical deterioration. We have previously documented our experience with intrathoracic tissue expanders for PPS management in children, and detailed our surgical technique[2,3].

Placement of such prosthesis is not without its attendant complication risks. They can be prone for mechanical issues, including excessive pressure if filled in beyond the accepted limits for the pleural cavity. Our practice had always been to fill in these prostheses to 50% of the estimated pleural volume initially, before returning the child to intensive care unit. Once returned, the clinical progress allows for extubation and further recovery, before further MLB assessment and guidance for reinflation: this allows for controlled filling thereby avoiding pressure effects. Infections can be catastrophic – though not documented as infective prosthesis in the single child who died in our series, any infection is always considered notorious in the presence of such foreign element in the chest cavity. Additionally, whenever such a prosthesis is considered as a delayed means for PPS, an important step to consider is the successful release of fibrotic elements within the pleural cavity; this would negate the contracture and allows for repositioning of mediastinum to central position allowing for better clinical recovery.

CONCLUSION

The use of tissue expanders is within the armamentarium of most plastic surgeons' practice. We also therefore advocate for a collaborative team approach involving Plastic and Cardiothoracic Surgery for surgical treatment of these patients. This multidisciplinary strategy has improved management of this rare and debilitating condition of PPS, thereby offering significant improvements in general progress of these sick children having single lung physiology. Evidence is still lacking on functional outcomes in these children and further work is necessary to prove that this is indeed achievable. .

Declaration Of Competing Interest

The authors have no conflicts of interest to declare.

FIGURE LEGENDS

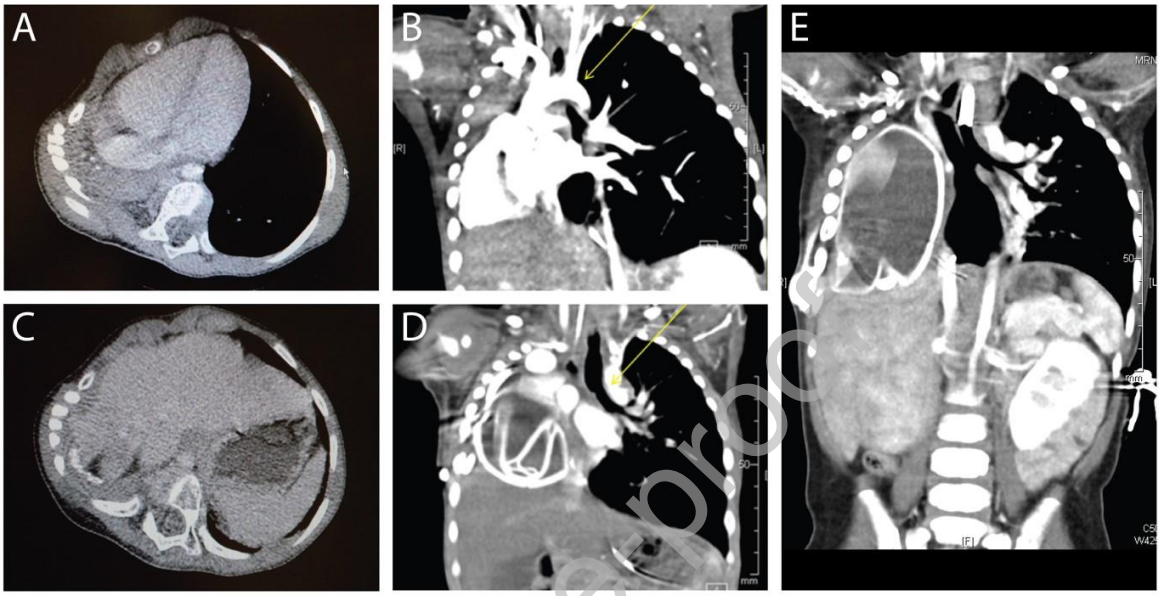

Figure 1. Computed tomography scan of patients with left sided physiologic single lung. Prior to intrathoracic tissue expander placement, the mediastinal contents have herniated into the right thoracic cavity (A, B). Following surgery, the prosthesis is well positioned within the chest, and the mediastinum has been restored to its normal anatomic position (C, D, E). With a centralised mediastinum, the trachea is well aligned, and there is relief of compression by vascular structures (yellow arrows).

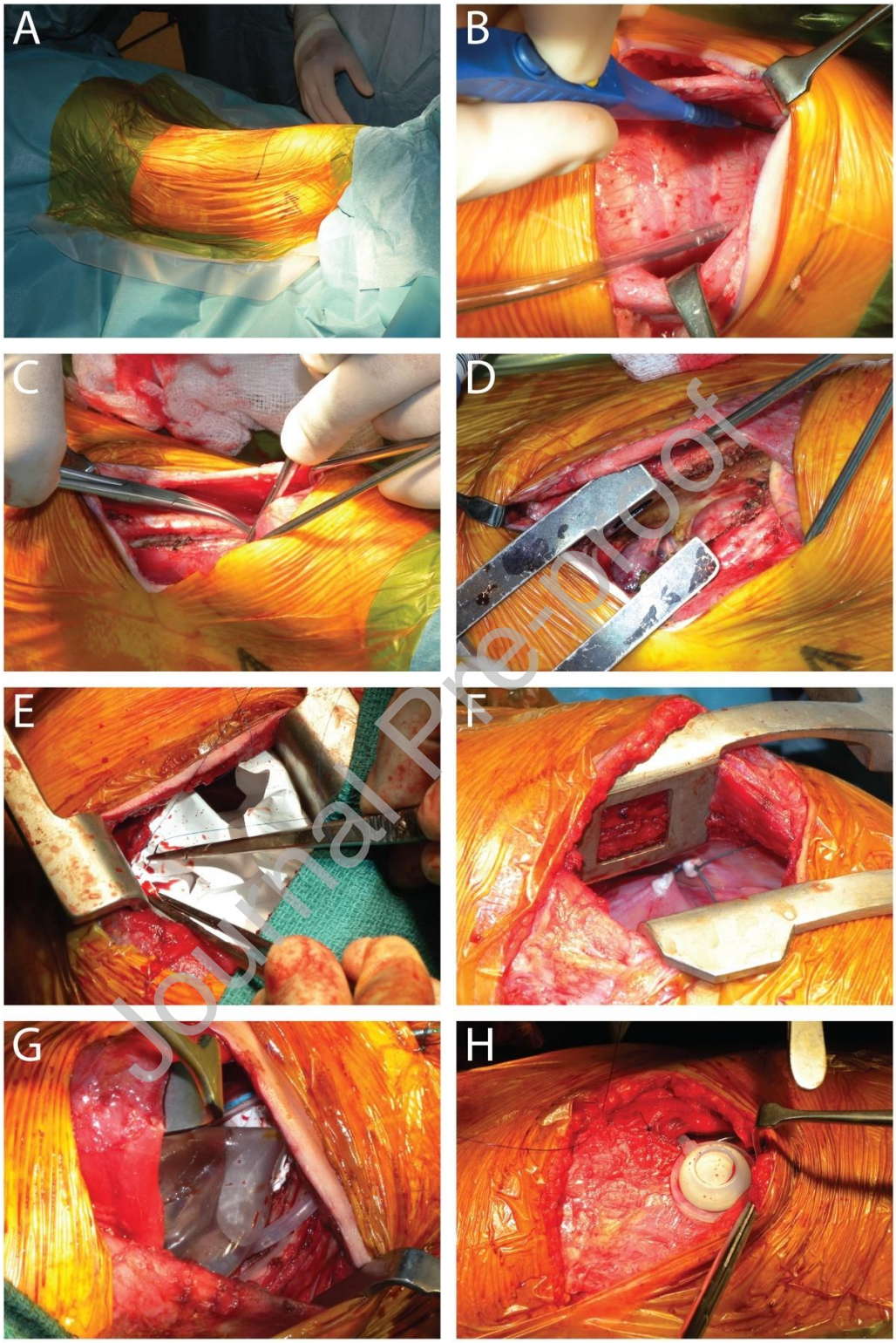

Figure 2. Surgical technique for intrathoracic tissue expander placement. The patient is placed in lateral decubitus, with the side with the absent lung facing up, and a horizontal lateral thoracotomy incision is marked (A). Skin flaps are raised, and a muscle-sparing approach is used to expose the latissimus dorsi and the serratus anterior (B). The 4th or 5th intercostal space is identified, and chosen as the entry point to the pleural cavity (C). Anterior adhesions are dissected (D), and the mediastinum is released and allowing it to rotate returning to a more normal central anatomical position, and pericardiopexy is performed (E, F). A pre-ordered expander, is placed into the thoracic cavity, and is filled gradually (G). The tissue expander port is passed though the intercostal incision. The serratus anterior and latissimus dorsi are allowed to assume their normal position and re-drape in a double-breasted manner. A pocket is then created inferiorly on the muscle fascia for the expander port which is sewn down to prevent rotation (H). The superficial fascia layer is closed followed by a dermal and subcutaneous suture.

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Table 1. Baseline and pre-operative characteristics (n = 24)

Female gender, n (%)	8 (33.3)
Age at First Airway Surgery, median (months) (range)	3.5 (3 – 108)
Weight at First Airway Surgery, median (kg) (range)	5 (3.1 – 36)
Prematurity at birth, n	2
Single lung etiology	
Agenesis, n (left:right)	6 (0:6)
Hypoplasia, n (left:right)	9 (1:8)
Postpneumonectomy, n (left:right)	9 (2:7)
Associated intrinsic (long segment) tracheal stenosis, n	7
Associated anomalies	
Cardiac, n	5
Non-cardiac, n	7
Pre-operative ventilation	12
Pre-operative ECMO, n	2
Pre-operative tracheostomy, n	0
Intraooperative procedures	
Pericardiopexy, n	24
Aortopexy, n	9
Sliding tracheoplasty, n	6
Intracardiac repair, n	5

Table 2: Surgery, post-operative recovery and outcomes (n = 24)

Primary airway surgery*

Slide Tracheoplasty, n	6
Simultaneous repairs	
Cardiac, n	4
Lung/Airway, n	4
Pneumonectomy of hypoplastic lung, n	7
Further airway interventions	
Airway dilatation, n	5
Airway stenting, n	3
Tracheostomy, n	7
Post-operative ventilation, mean (days) (range)	11 (1-87)
Post-operative ICU stay, mean (days) (range)	17 (1-60)
Post-operative ECMO, n	2
Positive pressure ventilation at discharge	
Tracheostomy, n	7
Nasal CPAP, n	3
Mortality at hospital discharge, n	1

CPAP: continuous positive pressure ventilation, ECMO: extracorporeal membrane oxygenation, ICU: intensive care unit

***Before placement of intrathoracic prosthesis**