Clinical Reports

Management of an infant with diffuse bullous pulmonary lesions using high-frequency oscillatory ventilation

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Purpose: To describe the anesthetic and ventilatory management of an infant with diffuse pulmonary bullous lesions.

Clinical Features: Four successive operations were scheduled for an infant with diffuse pulmonary bullous lesions. At the age of seven weeks, conventional positive pressure ventilation during laparotomy for intestinal occlusion led to arterial desaturation. This was corrected by returning to spontaneous respiration and deep inhalation anesthesia with halothane. Based on our ICU experience and due to a potential impaired oxygenation during conventional ventilation, we chose high-frequency oscillatory ventilation (HFOV) for bilateral sequential thoracotomies for bullectomies at the age of five months. We elected the same ventilatory mode for laparotomy for intestinal obstruction secondary to a polyp at the age of six months. This ventilatory mode was combined with total intravenous anesthesia and epidural analgesia and provided optimal oxygenation and ventilation as well as vital signs stability.

Conclusion: High frequency oscillatory ventilation is a safe technique that may be used in the operating room in cases where conventional ventilation failed to provide satisfactory gas exchange.

Objectif : Décrire la technique d'anesthésie et de ventilation chez un enfant souffrant de lésions bulleuses pulmonaires bilatérales.

Aspects cliniques : Un enfant porteur de lésions pulmonaires bulleuses diffuses a dû subir quatre opérations successives. À l'âge de sept semaines, la ventilation habituelle en pression positive utilisée durant une laparotomie pour occlusion intestinale a abouti à une désaturation artérielle. Le traitement a consisté en l'utilisation d'une technique d'anesthésie par inhalation d'halothane en respiration spontanée. En nous basant sur notre expérience aux soins intensifs et sur le fait que la ventilation traditionnelle pourrait provoquer une hypoxie, nous avons choisi d'utiliser la ventilation à haute fréquence par oscillations pour deux thoracotomies séquentielles pour bullectomies à l'âge de cinq mois. Nous avons choisi la même technique de ventilation pour une nouvelle laparotomie pour occlusion intestinale sur un polype à l'âge de six mois. Ce mode ventilatoire associé à une anesthésie intraveineuse totale et à une analgésie épidurale a permis d'assurer l'oxygénation et la ventilation du patient tout en maintenant la stabilité des paramètres vitaux.

Conclusion : La ventilation à haute fréquence par oscillations est une technique sécuritaire et utilisable en salle d'opération lorsque la ventilation classique ne permet pas d'assurer des échanges gazeux satisfaisants.

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HIGH-FREQUENCY oscillatory ventilation (HFOV) is a mode of ventilation using tidal volumes smaller than dead space to achieve gas exchange while trying to minimize lung injury by volutrauma.[8] It is recognized as a useful mode of ventilation in selected pathology of newborns and infants in the critical care setting such as hyaline membrane disease,[1] congenital diaphragmatic hernia (CDH),[2] persistent pulmonary hypertension of the newborn, meconial aspiration syndrome, neonatal lobar emphysema[3] and air leak syndrome.[4] Its shorter-term use in the operating room has only rarely been reported in the literature over the past few years for operations such as CDH, esophageal atresia repair,[2,5,6] and congenital cystic adenomatoid malformation of the lung.[7]

We report an infant with diffuse bullous lung disease who required anesthesia on several occasions. Because we experienced difficulty achieving adequate oxygenation using conventional ventilation during the first operation we elected to attempt HFOV. We describe a technique using this ventilatory mode in conjunction with total intravenous anesthesia (TIVA) and epidural anesthesia. Arterial PO_2 and PCO_2 were maintained at stable levels, without any ventilatory or hemodynamic complications.

Case Report

A seven-week-old girl, product of a full-term normal pregnancy was transferred from a community hospital to our pediatric university hospital for persistent fever (39°C) and an abnormal chest radiograph revealing bilateral, large, air-filled spaces (Figure 1). On admission, she weighed 4,850 kg, respiratory rate was 40·min^{-1}, heart rate 140·min^{-1} and SpO_2 97% (room air). Computerized tomography (CT scan) of the thorax revealed diffuse bilateral bullous lesions diagnosed as probable pneumatoceles (Figure 2).

During the hospital stay, she developed intestinal occlusion requiring emergency laparotomy for intussusception secondary to a polyp.

Rapid sequence induction of anesthesia using 0.08 mg atropine, 25 mg thiopental and 10 mg succinylcholine was followed by orotracheal intubation (tube 4.0 mm). Attempts to use conventional positive-pressure ventilation with an Ayre's T-piece led to arterial desaturation (SpO_2 - 60%). This was corrected by returning to assisted spontaneous breathing and surgery was resumed under deep inhalation anesthesia using halothane 2% via an Ayre's T-piece, peak pressure not exceeding 18 cm H_2O with fentanyl (1μg·kg^{-1}). This technique allowed the FiO_2 to be progressively reduced from 100% to 50% to obtain SpO_2 of 97-98%.

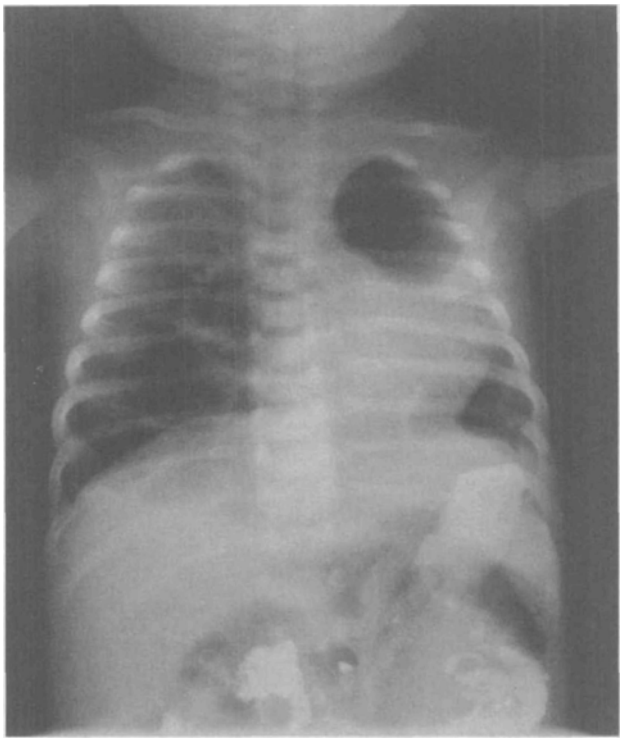

FIGURE 1 Preoperative chest radiograph at the age of seven weeks showing large bullae throughout both lungs. Note intestinal preparation for barium contrast series.

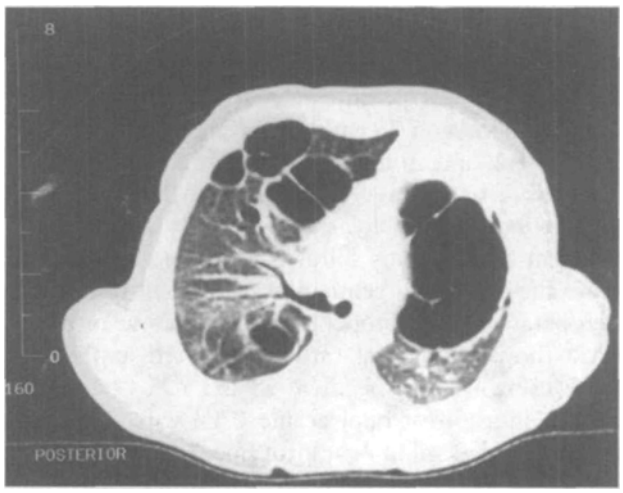

FIGURE 2 Computerized tomography of thorax at the age of seven weeks revealing multiple bullae compressing pulmonary parenchyma.

The procedure was well tolerated and the trachea was extubated in the recovery room 20 min after surgery. The SpO_2 was 99% with a FiO_2 of 40%. Analgesia was provided by 0.5 mg morphine *iv*. The postoperative period was uneventful and the child was discharged six days later.

Because of symptoms of respiratory decompensation over the next three months (tachypnea at 60·min^{-1}, intercostal and subcostal tirage, hypercarbia to 60 mmHg and hypoxia to SpO_2 90%) the infant was readmitted for biopsy of the pulmonary lesions and staged bilateral bullectomy to improve ventilatory function. A pre-operative echocardiogram showed normal cardiac contractility and no signs of pulmonary hypertension.

Left thoracotomy was performed at the age of five months, the child weighing 6 kg. Considering the previous anesthetic experience and fearing potential hypoxia, HFOV was chosen in an effort to minimize peak airway pressures with the benefit of a higher mean airway pressure. Anesthesia was induced with 18 mg propofol, 10 µg fentanyl and 10 mg succinylcholine and maintained with propofol in decreased doses from 200 to 125 µg·kg·min^{-1} and vecuronium (1 mg). A radial artery line was inserted for blood pressure monitoring and blood sampling. A thoracic (T8-T9) epidural catheter was inserted (using a 18G Tuohy needle and a 21G catheter) to provide intraoperative analgesia (bupivacaine 0.1% with 2µg·ml^{-1} fentanyl at 1-2 ml·hr^{-1}) and to allow extubation in the operating room. Epidural analgesia was maintained until removal of chest tubes on postoperative day four.

High-frequency oscillatory ventilation was performed through a standard endotracheal tube using a SensorMedics 3100A ventilator (SensorMedics Corp., Yorba Linda, CA). Parameter setup was adjusted according to our experience in pediatric intensive care. A frequency of 10 Hz, mean airway pressure of 13.5 cm H_2O, amplitude of 35 cmH_2O, Inspiratory/Expiratory ratio of 1:2, and an inspired oxygen fraction (FiO_2) of 1.0 were used. Arterial blood gases (ABG) were sampled periodically (Table I).

Right thoracotomy followed two weeks later. The same anesthesia and ventilation techniques were used. Peroperative and postoperative analgesia was provided via a thoracic epidural catheter inserted at the T_{8-9} level (using a Tuohy needle # 18 and a 21 G catheter) and an infusion of bupivacaine 0.1% with 2 µg·ml^{-1} fentanyl at 1-2 ml·hr^{-1}. Improvement in oxygenation compared with the previous thoracotomy is shown in the Table. A right pneumothorax required chest tube drainage on postoperative day eight. This procedure lasted one hour and was performed under deep sedation with intravenous ketamine (5 mg *iv* repeated as necessary to a total dose of 25 mg). Respiration was spontaneous via a Ventimask (FiO_2 40%) and SpO_2 was 95-96%.

TABLE Blood gas tensions

Event	*FiO_2*	*SpO_2*	*pH*	*PaO_2*	*$PaCO_2$*	*art/cap*
Laparotomy #1						
pre-op	0.21	97	7.47	69	35	cap
post-op	1.00	99	7.37	87	49	cap
L thoracotomy						
pre-op	0.30	94	7.31	80	75	cap
per-op	1.00	100	7.44	80	55	art
post-op	0.60	100	7.34	157	57	art
R thoracotomy						
pre-op	0.21	93	7.40	63	43	cap
per-op	1.00	100	7.40	240	42	art
post-op	0.90	100	7.35	211	52	art
Chest tube insertion						
pre-op	0.35	95	7.39	74	51	cap
post-op	0.35	96	7.36	84	48	cap
Laparotomy #2						
pre-op	0.21	91	7.42	60	45	cap
per-op	1.00	98	7.30	232	50	art
post-op	0.90	98	7.32	108	50	art
Discharge	0.21	96	7.42	66	40	cap

FiO_2: inspired O_2 fraction
SpO_2: Hemoglobin saturation by pulse oximetry (%)
PaO_2: Arterial partial pressure of oxygen (mmHg)
$PaCO_2$: Arterial partial pressure of CO_2 (mmHg)
art.: arterial blood sample cap.: capillary blood sample

A second episode of intestinal occlusion secondary to a polyp required another laparotomy at six months of age. Rapid sequence induction of anesthesia was followed by the same anesthetic and ventilatory management as for the thoracotomies. A lumbar (L_{3-4}) epidural catheter was inserted (18G Tuohy needle, 21G catheter) to facilitate extubation in the operating room and to ensure adequate postoperative analgesia for two days (bupivacaine 0.1% with 2 µg·ml^{-1} fentanyl at 1-2 ml·hr^{-1}). On postoperative day seven the patient was discharged.

The histopathological examination of the pulmonary lesions revealed pulmonary blastoma. The patient has undergone chemotherapy.

Discussion

Choosing an anesthetic technique given this child's pulmonary pathology was a challenge. Conventional ventilation, as attempted during her first operation was unsuccessful, as reflected by decreases in SpO_2. Large tidal volumes, positive inspiratory pressure and prolonged expiratory time due to lack of elastic pul-

monary recoil were thought to promote hyperinflation of the bullae. We believe hyperinflation impeded ventilation of the surrounding parenchyma hence impairing gaseous exchange in the alveoli. The pathophysiology of the respiratory anomalies and anesthetic implications were thus considered to be similar to those of emphysema.

Thoracic surgery requires the anticipation of respiratory physiology at each step of the intervention. Numerous factors are expected to impair gas exchange during the operation. Lobectomy was to be performed in the lateral decubitus position, shifting a large fraction of blood flow to the dependent lung thus promoting right-to-left intrapulmonary shunt. Moreover, this lung is trapped under the weight of the mediastinum and tends to collapse secondary to the surgical manipulation of the nondependent lung. In this case, since disease affected both lungs equally, the dependent lung was expected to have decreased function already. Gross movement and the bulge of an overinflated lung would have hindered surgery. For these reasons and because of the hypoxia noticed during the previous use of positive pressure ventilation, we were reluctant to use conventional two-lung ventilation. One-lung ventilation (OLV) in this age group is rarely performed due to the small bronchi and the unavailability of double-lumen tubes. Although feasible, selective mainstem bronchus intubation would require delivery of higher tidal volumes, ventilatory rates and peak airway pressures which could be detrimental to the dependent lung. General anesthesia using volatile agents with spontaneous breathing in the lateral decubitus position and an open thorax would not provide adequate ventilatory mechanics or gas exchange. Cardiopulmonary bypass was felt to carry an unacceptable risk of hemorrhage.

Considering these constraints, we elected to attempt HFOV. High frequency ventilation (HFV) is "a mode of ventilation at respiratory rates > 1 Hz ($60 \cdot min^{-1}$) and at tidal volumes < dead space volumes".[6] Lung volume is maintained above functional residual capacity by the use of a constant distending pressure determined by mean airway pressure. The avoidance of high lung volumes prevents volutrauma by overinflation of the more compliant lung units, and the avoidance of low lung volumes prevents collapse of the less compliant lung units. Ventilation-perfusion matching is improved, dead space volume is decreased, and gas exchange is maintained with less lung injury.[8] Our experience with HFOV in the pediatric intensive care unit and our search of the literature prompted us to use it in the operating room.

The SensorMedics 3100A we used is a piston-diaphragm oscillator. Slutsky[9] postulated that gas exchange occurs mainly through convection in HFV whereas conventional ventilation implies bulk flow. Mechanisms differ according to airway calibre and turbulence of gas flow. The pressure oscillations are superimposed on the mean airway pressure (MAP). Exhalation is active in HFOV, possibly reducing air trapping[10] and HFOV is delivered through a standard endotracheal tube in the pediatric patient. The FiO_2, MAP, pressure amplitude, frequency and inspiration to expiration ratio can be adjusted. End-tidal CO_2 cannot be monitored during HFOV.[8] Thus, arterial blood gases must be sampled frequently, which constitutes an important drawback. Transcutaneous monitoring of CO_2 could be envisioned but the reliability of this technique seems variable.[11] Volatile-based anesthesia cannot yet be coupled to HFOV. We therefore opted for TIVA.

The benefits of HFOV are being more widely accepted for selected respiratory diseases of the newborn in the neonatal intensive care unit. Several European reports of HFOV in pediatric surgery have yielded good results with adequate operating conditions, especially in congenital diaphragmatic hernia and tracheo-esophageal fistula repair.[5] Recently, successful anesthesia for surgery of cystic adenomatoid malformation of the lung was provided using HFOV.[7] The intervention was carried out in the neonatal intensive care unit to avoid transport-related complications. We experienced no technical failure during the procedures. The surgeons adapted rapidly to the lung vibrations with HFOV as has been suggested in previous reports.[5,7] Vital sign and SpO_2 monitoring showed cardiorespiratory stability and were not significantly affected by the vibrations.

The selection of patients for alternate ventilatory method other than conventional positive pressure ventilation can be difficult. We think that the ventilatory mode used in the intensive care unit is often the best way to oxygenate and to ventilate a patient. In these selected cases, the unusual ventilatory mode can be brought to the operating room. Using HFOV with TIVA and epidural anesthesia for an infant with cystic pulmonary lesions undergoing sequential bilateral thoracotomies proved to be safe and effective. We were reluctant to repeat conventional ventilation after hypoxia was encountered during the first laparotomy. However successful our attempt was, we cannot conclude on the superiority of HFOV over conventional ventilation on the basis of this limited experience. Our outcome confirms that HFOV is an option to consider should conventional ventilation fail. If confronted with other difficult pulmonary pathology such as CDH, pulmonary air leaks or emphysematous disorders we would consider bringing HFOV back to the operating room.

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