Resolution of Pulmonary Overinflation in an Extremely Low-Birth-Weight Infant Utilizing a 'Lung Squeezing' Technique — A Case Report

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Abstract: Uneven distribution of ventilation in infants ventilated with high-frequency oscillation may be presented as regional overinflation of the lungs. Current evidence supports that inflation pattern aberrations and pseudocyst formation are pathologic lesions associated with ventilator-induced lung injuries. Physiotherapy with a 'lung squeezing' technique was utilized to reduce the regional overinflation in a preterm infant of extremely low birth weight. The infant responded with complete resolution of the regional overinflation and improved homogeneous distribution of ventilation. This single case report suggests that the lung squeezing technique may be useful in promoting normal lung inflation in preterm infants receiving high-frequency oscillation.

Key words: physiotherapy, neonate, lung squeezing technique, regional overinflation

Case Report

Baby N was a male infant born at a gestation of 22 5/7 weeks, weighing 650 g. His mother presented with a history of cervical incompetence. Cervical cerclage was attempted but unsuccessful, and premature spontaneous rupture of membrane was unavoidable. The baby's Apgar Scores were 3, 5 and 5 at one, five and ten minutes respectively. The infant was then placed on high frequency oscillatory ventilation (Model 3100A, SensorMedics Corp, Yorba Linda, CA, USA) and stabilized with FiO_2 of 0.35, mean airway pressure 13 cm H_2O at a ventilatory rate of 15 Hz and 33% fractional inspiratory time. Initial chest X-ray demonstrated features of grade II respiratory distress syndrome. Two doses of surfactant were given at 30 minutes and 12 hours after birth respectively.

On day 21, ventilator settings were weaned to FiO_2 0.23 and mean airway pressure 8.1 cmH_2O. The ventilatory rate was maintained at 15 Hz and the fractional inspiratory time was unchanged. However, chest films revealed left upper lobe haziness and collapse of the right upper lobe. Upon examination, breath sounds were decreased over the upper chest bilaterally.

On day 22, chest x-ray (Fig. 1) revealed collapse of both upper lobes, and a marked hyperinflated right lung base with a circular border. A lateral chest film (not shown) confirmed the absence of pneumothorax. Clinically, this circular cyst did not appear to compromise any cardiovascular function, the infant maintained a stable heart rate of 150-160 beats per minute and blood pressure was around 56/39(49) mm Hg [systolic/diastolic (mean)]. Blood gas values were: pH 7.297, PaO_2 7.71 kPa, $PaCO_2$ 6.65 kPa, base excess –3.1 mmol/L and SpO_2 94%. Visual examination also suggested that the right lung base was hyperinflated and accompanied by a decreased oscillation compared to the left lung base. To minimise the regional overinflation, the mean airway pressure was decreased to 7.5 cm H_2O.

Chest physiotherapy was initiated immediately after the reduction of ventilator pressure. A 'lung squeezing' technique was employed with the objective of re-ex-

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panding the atelectatic region and to achieve a more even distribution of ventilation, and hopefully, to facilitate a further reduction of the ventilatory airway pressure. No endotracheal suctioning was performed during physiotherapy as the infant did not present with any secretion problems. The 'lung squeezing' technique consisted of chest wall compressions applied specifically to the hyperinflated lung region. This technique differs from the conventional chest wall compressions employed by physiotherapists in the following aspects: (1) Each set of 'lung squeezes' consisted of three to four sustained chest compressions lasting for about five seconds, followed by a gentle slow 'release phase' with the chest wall being completely released. (2) These compressions were given without vibration and not in a gravity-assisted position. (3) Delivery of the chest compressions was not intended to be in synchrony with the infant's breathing pattern. The manoeuvre was repeated for a total of 10 minutes.

Physiological responses to this technique were monitored to ensure a variation of heart rate at less than 20% of the baseline value, arterial saturation above 90%, and the mean blood pressure at above 45 mmHg. No adverse physiological responses were observed throughout the therapy session. Despite no change in supplemental oxygen concentration, SpO_2 improved to more than 98% at the end of the treatment session. Lung oscillations over both lung bases were observed to be symmetrical after lung squeezing. A chest film taken three hours later revealed complete resolution of the lung cyst, although the bilateral upper lobes remained collapsed (Fig. 2). Subsequent chest films did not show any recurrence of the lung cyst. The infant was ventilated with a mean airway pressure of 7.5 cmH_2O for the next 12 hours.

The 'lung squeezing' technique was continued and delivered twice daily by the same therapist, with the aim of re-expanding the atelectatic lobes. Three days later (Day 25), a chest film (Fig. 3) revealed full expansion of both upper lobes and improved aeration over both lung fields. Ventilatory airway pressure was gradually weaned to 4 cmH_2O within 12 hours. There was no recurrence of any regional overinflation. The infant was successfully extubated to nasal CPAP on day 30 of life.

Discussion

High-frequency ventilation has been employed in the management of neonatal respiratory distress for the past decade. High-frequency ventilation may allow adequate gaseous exchange at lower airway pressures than conventional ventilation [3]. The ventilatory mode is widely used for very low-birth-weight infants for the purpose of minimizing ventilator-induced lung injuries [4–6]. In high-frequency oscillatory ventilation (HFOV), the active exhalation phase generated by a piston or diaphragm is thought to prevent gas trapping to some extent [7]. The use of a smaller inspiratory/expiratory ratio may also help to reduce gas trapping by providing a longer expiratory time [8].

A multicentre, prospective, randomized study was conducted to determine whether HFOV would decrease the development and progression of air leak syndromes (ALS) in infants with severe respiratory distress syndrome [9]. The study demonstrated that HFOV using a "high-volume strategy" decreased the development of ALS in these infants by 21% when compared to conventional ventilation. However, for infants who were suffering from ALS upon recruitment into the study, there was no evidence that HFOV accelerated the resolution of ALS. The near-constant distending pressure generated

Fig 1. Chest film showing bilateral upper lobar collapse, regional overinflation and hyperexpanded radiolucencies at right lung base.

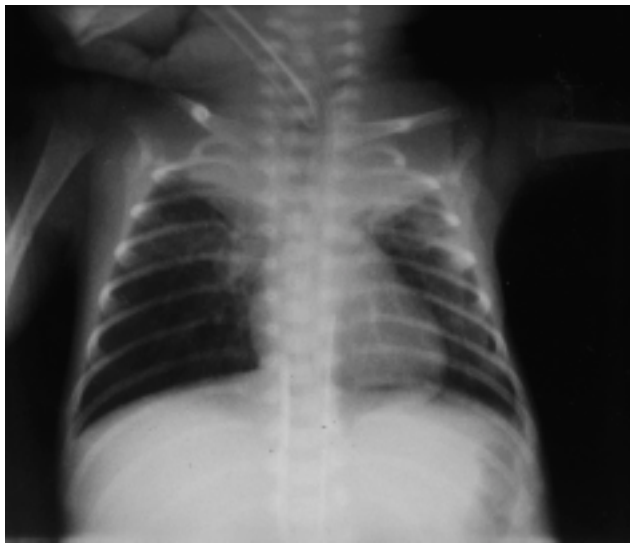

Fig 2. Chest film three hours after delivery of lung squeezing physiotherapy: hyperexpanded radiolucencies over right lung base resolved.

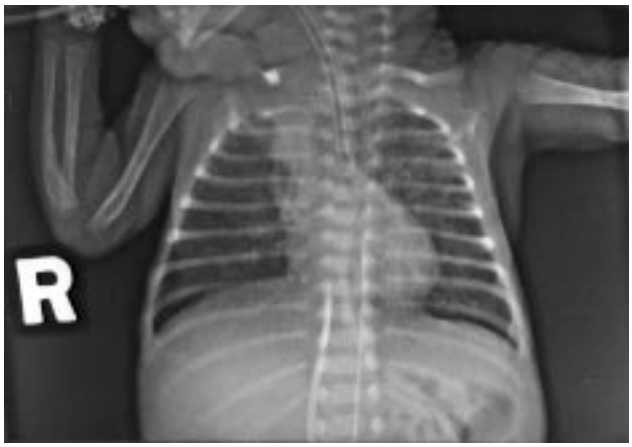

Fig 3. Chest film three days later showing complete resolution of bilateral upper lobar collapse and a more homogeneous distribution of ventilation.

by high-frequency oscillations has been used as a 'volume recruitment manoeuvre' to optimize alveolar re-expansion [10] and to promote uniform lung inflation. In our experience, despite the adoption of an optimal lung inflation ventilating pattern, lobar collapse may still occur and co-exist with regional overinflation during HFOV. A possible cause can be the inhomogeneous distribution of exogenous surfactant [11]. Mucostasis may also cause airway obstruction leading to regional gas trapping or atelectasis. This phenomenon of uneven distribution of ventilation may present a great challenge to therapists. Excessive regional overinflation can be a severe manifestation of uneven distribution of ventilation, and the resultant space-occupying effect may compress on adjacent alveolar units and predispose to atelectasis [12]. Uncorrected regional overinflation may subject the infant to high transpulmonary pressures and progress to other air leak syndromes [13].

Physiotherapy using the lung squeezing technique described in this report has been shown to be effective in correcting atelectasis in ventilated infants [14]. In a previous study [15], we investigated the changes in pulmonary mechanics in clinically stable infants with respiratory distress syndrome. We demonstrated that a 10-minute session of the lung squeezing technique immediately improved the mean respiratory system compliance by 21%. The improvement in lung compliance might be attributed to a more homogeneous distribution of ventilation and enhanced mucus clearance of the small airways. In this case report, the lung squeezing manoeuvre was delivered to the overinflated right lung base. The purpose was to reduce the regional gas trapping by external restriction of the hyperinflated lung region. We hypothesized that during the delivery of lung squeezing, unrestricted alveoli with slower time-constants are provided with an opportunity to inflate, thus promoting a more homogeneous gas distribution in lung regions.

Management of hyperinflated lungs by positioning in patients with unilateral tension pulmonary interstitial emphysema has been reported [16]. The authors hypothesized that external restriction of the chest wall could contribute to the resolution of the emphysema. However, because these patients were also managed by reduced airway pressure, it could be argued that the improvement in lung hyperinflation was not solely the result of external chest wall restriction. Animal studies have shown that enhanced mucus clearance is observed in high-frequency oscillation incorporated with external chest compressions [17]. This increase in mucus clearance rate might be due to a cephalad bias in airflow and a greater peak expiratory airflow when compared to inspiratory airflow. Although the underlying mechanism of reducing regional overinflation by delivery of external chest compressions was unclear, we speculated that this cephalad airflow bias might be related to a reduction in gas trapping.

In this clinical scenario, although one may argue that the resolution of regional overinflation could have been caused primarily by the reduction of ventilatory pressure, the improvement in arterial saturation and the improved symmetry of bilateral chest wall movement immediately after the application of the lung squeezing technique provided evidence for the positive contribution of this technique in the resolution of hyperinflation. Further studies controlling the ventilatory airway pressure are therefore essential to support the beneficial effect of the lung squeezing technique.

Preferential distribution of regional overinflation and atelectasis in ventilated neonates has been reported in both respiratory distress syndrome and bronchopulmonary dysplasia conditions [18]. Based on ^{133}xenon lung scans, Moylan and Shannon deduced that the lobar hyperinflation was due to emphysema, rather than a compensatory mechanism for the collapsed lobes. All these neonates were ventilated with conventional positive pressure ventilation. The pattern of preferential distribution of ventilation suggests that the causative mechanisms may be similar in both conventional ventilation and HFOV. Little is known about the aetiology and natural history of these ventilation abnormalities. Recently, bronchoscopic findings suggest that bronchomalacia may contribute to lobar overinflation in bronchopulmonary dysplasia [19]. It is possible that dynamic airway collapse on the overinflated side is related to asymmetrical air trapping.

Other therapeutic concerns that have been brought to our attention are: (1) Of the 17 infants in Moylan and Shannon's study, four had ventilation abnormalities persist for more than eight weeks. It implies that, if the phenomenon is left uncorrected, the overinflated area will inevitably be exposed to a higher risk of ventilator-induced injuries. (2) These ventilation abnormalities can cause reverse mismatch in pulmonary ventilation/perfusion [20], resulting in hyperperfusion to the atelec-

tatic area [21, 22]. In severe cases, the extensive right-to-left shunting may result in hypoxaemia and respiratory deterioration. Although it is not known if untreated regional overinflation will exaggerate over time, immediate intervention in ventilation abnormalities and overinflation is imperative and will promote better ventilation/perfusion matching.

Conclusion

A 'lung squeezing' technique which restricts localized chest wall movements was employed on a preterm neonate with regional lung overinflation and complete resolution was achieved after one session of treatment. Further studies to explain the underlying mechanisms are necessary.

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