Respiratory Medicine Case Reports 22 (2017) 133–136

Contents lists available at ScienceDirect

Respiratory Medicine Case Reports

journal homepage: www.elsevier.com/locate/rmcr

Case report

Efficacy of lung volume optimization maneuver monitored by optoelectronic pletismography in the management of congenital diaphragmatic hernia

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A R T I C L E I N F O

Article history:
Received 19 June 2017
Received in revised form
25 July 2017
Accepted 26 July 2017

Keywords:
CDH
Lung volume
Ventilation strategy
Newborn
Opto-electronic plethysmography

A B S T R A C T

Newborns affected by congenital diaphragmatic hernia (CDH) need cardio-respiratory stabilization before undergoing surgical repair. Open lung strategy is a well-established approach to optimize lung volume in preterm infants with Respiratory Distress Syndrome (RDS), using both High Frequency Oscillatory Ventilation (HFOV) and Conventional Mechanical Ventilation (CMV).

We report a case of left CDH with severe lung hypoplasia, managed applying open lung strategy in HFOV (pre-surgery period) and in Assist-Control with Volume Guarantee (post-surgery period), guided by SpO_2 changes, $TcPO_2$ and $TcPCO_2$ monitoring. Opto-electronic plethysmography was used to measure end-expiratory chest wall volume changes (ΔEEcw) related to lung volume variations occurring during pressure changes. OEP confirmed the efficacy of using SpO_2 and transcutaneous gas monitoring during this recruitment maneuver.

1. Introduction

Survival in patients affected by Congenital Diaphragmatic Hernia (CDH) ranges from 60 to 70% [1], and the main causes of death are related to lung hypoplasia and pulmonary hypertension [2].

Cardio-respiratory stabilization before surgical repair, in fact, is a crucial step for newborns affected by CDH [3,4]. During the first hours of life all infants with severe disease require mechanical ventilation to establish normal gas-exchange. Moreover, the achievement of an adequate lung volume is crucial for these neonates' survival. Hence, the aim of the first hours' management is to optimize blood oxygenation and recruit lung volume, avoiding volu-barotrauma related injuries [4].

The "open lung strategy" has been demonstrated to be an effective procedure to recruit the lung in preterm infants with Respiratory Distress Syndrome (RDS) [5]. This technique can be performed while on High Frequency Oscillatory Ventilation (HFOV) or Conventional Mechanical Ventilation (CMV) and it consists of setting the lung volume on the deflation limb of the P-V curve.

The successful use of HFOV before surgery in CDH affected patients has been well described by Reye et al. and Miguet et al. [6,7]. However, the efficacy of this recruitment maneuver in both HFOV and CMV during the stabilization phase and after surgical repair hasn't been previously monitored in these patients.

We describe a case of left CDH with severe lung hypoplasia which has been managed applying a high lung volume strategy under the guidance of SpO_2 changes and $TcPO_2$/$TcPCO_2$ monitoring.

These changes were recorded by Opto-electronic plethysmography (OEP), which measures the end-expiratory chest wall volume variations (ΔEEcw) on a breath-by-breath basis [8]. These changes have shown to be correlated with lung volume variations in mechanically ventilated adult patients with RDS [9] and in the post-surgery follow-up of children affected by CDH at birth [10].

2. Case report

We describe the case of a female infant, born at 37 weeks of gestational age (GA) with antenatal diagnosis of CDH at 20^{+4} weeks' gestation. Fetal ultrasound and magnetic resonance imaging revealed left-sided CDH with severe lung hypoplasia (stomach, intestine, left lobe of liver in the thorax with mediastinal shift). Lung area to head circumference ratio (LHR) = 1.3 with observed/

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http://dx.doi.org/10.1016/j.rmcr.2017.07.013
2213-0071/

Abbreviations

BW	Birth Weight
CDH	Congenital Diaphragmatic Hernia
CMV	Conventional Mechanical Ventilation
ΔEEcw	end-expiratory chest wall volume variations
FiO_2	Fraction of inspired Oxygen
GA	Gestational Age
HFOV	High Frequency Oscillatory Ventilation
iNO	inhaled Nitric Oxide
LHR	lung area to head circumference ratio
NICU	neonatal intensive care unit
PEEP	positive end expiratory pressure
PIP	peak inspiratory pressure
P-V curve	Pressure-Volume curve
RDS	respiratory distress syndrome
SpO_2	pulse oxygen saturation
$TcPO_2$	transcutaneous oxygen pressure
$TcPCO_2$	transcutaneous carbon dioxide pressure
VG	volume guarantee

expected LHR = 0.7. No other congenital anomalies were detected.

Birth weight (BW) was 2645 g. She was intubated immediately after birth and positive pressure ventilation was given by T-piece resuscitator (Neo-puff, Fisher & Paykel) set on PIP = 25 cmH_2O, PEEP = 5 cmH_2O with FiO_2 = 1.0. APGAR score at 1-5-10 minutes = 5-8-9.

At 10 minutes of life SpO_2 was 88–90% with FiO_2 = 0.5. At 25 minutes of life the infant was transferred to NICU and HFOV was immediately started (Sensor Medics 3100 A, Care Fusion) with a high lung volume strategy using incremental and decreasing Continuous Distending Pressure (CDP) maneuver [11]. HFOV was started with CDP = 13 cmH_20, FiO_2 = 1.0, amplitude (ΔP) = 30 cmH_20, frequency = 10 Hz. Targets for SpO_2 and $TcPCO_2$ were ≥95% and 40–65 mmHg respectively.

During the *"first phase"* of the maneuver, CDP was stepwise increased by 1 cmH_20 (on average every 5 minutes) and FiO_2 progressively decreased until FiO_2 requirement was 0.3, maintaining SpO_2 and $TcPCO_2$ targets. After echocardiographic assessment of pulmonary hypertension, inhaled Nitric Oxide (iNO) administration was started at 20 ppm. During the *"second phase"*, CDP was progressively decreased by 0.5 cmH_2O (on average every 5 minutes) until FiO_2 had to be increased to maintain SpO_2 and $TcPCO_2$ targets. This moment was considered the 'critical closing pressure point'.

During the *"third phase"*, the lung was recruited again and stabilized with stepwise increments of CDP by 0.5–1 cmH_2O above the critical closing pressure point, decreasing FiO_2 until 0.3. SpO_2 and $TcPCO_2$ targets were maintained in range during this phase, as well (Fig. 1).

Throughout the whole maneuver, mean non-invasive blood pressure was stable above 50 mmHg. The complete maneuver lasted 3 hours and 20 min and the optimal CDP was established at 14 cmH_2O. During the whole maneuver the infant was monitored with OEP. Through the analysis of ΔEEcw measurements, this device provided estimated variations of end-expiratory lung volume at different CDP levels.

Surgery was performed on day 3 via conventional open abdominal approach. A large diaphragmatic defect was repaired with a prosthetic patch. On day 13 the infant was switched from HFOV to CMV, in Assist-Control with volume guarantee (VG) (Vt = 4.5 ml/Kg) (VN 500, Draeger) with initial PEEP = 5 cmH_2O. The optimal PEEP was found through stepwise incremental and decreasing changes of 0.2 cmH_2O on average every 5 minutes [10], using the same strategy describe above for HFOV, always guided by SpO_2 changes and $TcPO_2$/$TcPCO_2$ monitoring. The complete maneuver lasted 1 hour and the optimal PEEP was equal to 4 cmH_2O. OEP was used to measure ΔEEcw at different PEEP levels (Fig. 2).

3. Discussion

CDH is a severe respiratory and cardiovascular disorder and the proper ventilation management is crucial to ensure normal gas-exchange avoiding additional lung injuries. The lung hypoplasia secondary to the viscera herniation in the thorax is associated with abnormal development of the pulmonary vascular bed, and both these anomalies cause pulmonary hypertension. Moreover, the risk of lung hyperinflation related to high volumes can worsen the cardiovascular function and lead to hypoxia and hypercapnia.

Surgical repair remains the life-saving intervention in CDH. However, it has been well described that a delayed surgical treatment after stabilization with HFOV is a safe and effective strategy for better outcomes [6,7].

In fact, a "gentle" lung recruitment with oscillatory ventilation reduces the volume and barotrauma and minimize the effects of ventilator-induced lung injury (VILI), which are additional causes of morbidity and mortality in CDH infants [11]. Although the efficacy of HFOV in the pre-surgical phase has been widely established, to our knowledge the monitoring of the "recruitment maneuver" during lung volume optimization strategy has not been described in these patients, neither before nor after surgery.

The search for the "optimal and safe lung volume" with the minimal CDP which can provide adequate gas exchange with the lowest FiO2 could be, in fact, a useful method to avoid further lung injuries.

In the pre-surgery period, during HFOV, we have set the initial CDP close to 13 cmH_2O in agreement with the most recent recommendations [12]. Then, according to our guidelines, as soon as the infant is stable after surgical repair, we switch from HFOV to VG-CMV.

In order to reach the optimal PEEP level and the minimal FiO_2 to maintain the SpO_2 target, we use SpO_2 changes and $TcPO_2$/$TcPCO_2$ monitoring.

To date, it is impossible to establish at the bedside the adequate and safe lung volume to deliver. SpO_2 changes and $TCpO_2$/$TcPCO_2$ monitoring are the only available parameters for choosing the lowest pressure to set the lung volume on the deflation limb of the P-V curve.

Opto-Electronic Plethysmography, which has been recently successfully applied in the follow up of children with previous surgical repair of CDH [10], gives an accurate estimation of lung volume variations from thoraco-abdominal motion analysis.

In this case report, we have confirmed with OEP that a high lung volume ventilation strategy can be guided by SpO_2 and transcutaneous gas monitoring. However, OEP was not used to adjust ventilation in real time, since its data were retrospectively analyzed.

4. Conclusion

A recruitment maneuver with high lung volume strategy using HFOV guided by SpO_2 and $TcPCO_2$ monitoring seems to be a promising approach not only in the treatment of RDS in preterm babies, but also for the early respiratory stabilization of infants affected by CDH. Thanks to OEP measurements, this maneuver has

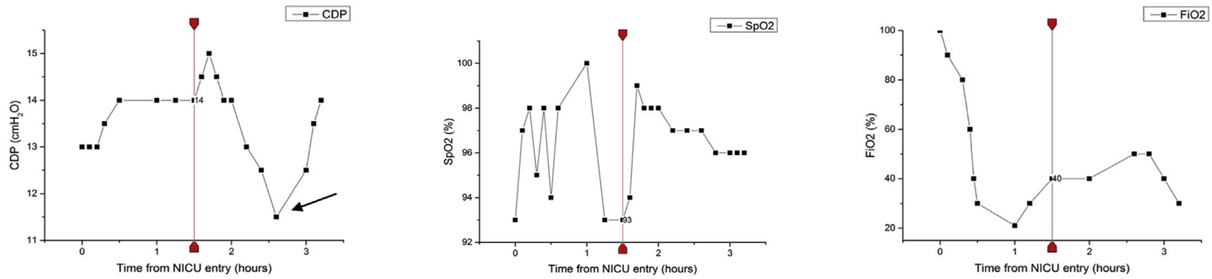

Fig. 1. Continuous distending pressure (CDP), fraction of inspired oxygen (FiO2) and pulse oxygen saturation (SpO2) during the three phases of the high lung volume strategy maneuver in HFOV. The vertical line indicates the start of inhaled nitric oxide (iNO). The black arrow points out the *"critical closing pressure point"*.

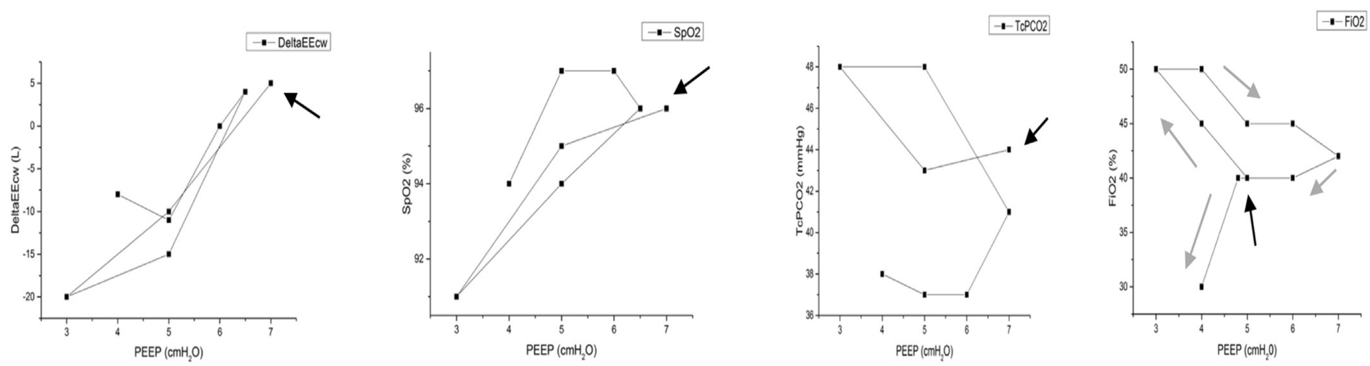

Fig. 2. End-expiratory chest wall volume variation (ΔEEcw), pulse oxygen saturation (SpO_2), *trans*-cutaneous partial pressure of carbon dioxide ($TcPCO_2$) and fraction of inspired oxygen (FiO_2) during high lung volume strategy after surgery in CMV. Driving pressure is positive end-expiratory pressure (PEEP) and it is reported on the x-axis. The black arrow indicates the starting point and the grey ones clarify the direction of the maneuver.

shown to be effective both in the acute phase before surgery and in the recovery phase after surgical repair. Infact, OEP data have confirmed the efficacy of the recruitment maneuver and the reliability of the parameters we use in routine clinical practice to guide this kind of ventilator's adjustments.

Even if pulmonary hypertension caused by lung hypoplasia needs to be diagnosed and treated with specific medical interventions, this ventilation strategy is helpful in finding the correct CDP level to recruit the lung avoiding further injuries.

Even if not in real time, Opto-electronic plethysmography could be useful to confirm this strategy when only SpO_2 and trans-cutaneous gas monitoring are available.

Funding source

No funding was secured for this study.

Financial disclosure

Authors declare no financial relationship relevant to this article.

Conflict of interest

Authors have no conflicts of interest to disclose.

Contributor's statement

Dr. Lista and Prof. Aliverti conceived the study and drafted the initial manuscript.

Dr. Bresesti critically reviewed the manuscript and revised the initial draft.

Dr. Cavigioli, Dr. Castoldi and Dr. Lupo helped with the coordination of the project and critically discussed the manuscript.

Dr. Lo Mauro e Prof. Aliverti were responsible for applying optoelectronic plethysmography, extracted the data and performed the data analysis.

All authors have read and approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

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