Intraoperative extracorporeal carbon dioxide removal support for minimally invasive surgical treatment of vanishing lung syndrome

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Abstract

Vanishing lung syndrome is a rare disease that could be treated successfully in selected cases with bullectomy. Protective ventilation is very important during surgery to achieve optimal post-operative results and to prevent complications. Hypercapnia and respiratory acidosis are the main disadvantages of this ventilator strategy. The use of extracorporeal CO₂ removal device has been introduced to support protective and ultra-protective ventilation during respiratory failure in complex cases. In thoracic surgery the intraoperative use of this device is still not widespread. We report a successful case of a giant left lung bullectomy with intraoperative support with Pro-Lung CO₂ removal device for the management of hypercapnia during single lung ventilation.

Keywords ECCO₂-R · Bullectomy · Vanishing lung syndrome · Extracorporeal carbon dioxide removal · Minimally invasive thoracic surgery

Introduction

Giant bullous emphysema or vanishing lung syndrome (VLS) is a rare disease with complex pathophysiology and challenging treatment options based on clinical presentation [1]. Giant bullectomy is a therapeutic option for selected patients affected by VLS [2]. Generally, a various amount of emphysema is present in both lungs and giant bullae can be bilateral. Surgery should be performed first on the most affected lung to achieve single lung ventilation and reduce the risk of intraoperative or post-operative complications [2, 3]. Nevertheless, intraoperative mechanical ventilation requires low tidal-volume (TV) to avoid hyperinflation and

to prevent pneumothorax on the ventilated lung [4]. In the last years, extracorporeal lung support has gained a wider diffusion in thoracic surgery and in particular the intraoperative use of carbon dioxide removal devices has been reported in complex surgical procedure to achieve ultra-protective ventilation preventing hypercapnia and respiratory acidosis [5]. We report a case VLS patient in which ultra-protective ventilation and a carbon dioxide removal device (ECCO₂-R) were used in combination to manage hypercapnia and respiratory acidosis during surgical bullectomy on single lung ventilation.

Case

A 36-old Caucasian man, affected by VLS, was referred to us from a tertiary center for lung transplantation evaluation. He was a former smoker with a history of 14 packs per 21 years. The computed tomography of the chest showed diffuse lung emphysema with heterogeneous distribution and giant bullae, on the left side a giant bulla had occupied approximately 95% of the hemi thorax with almost complete atelectasis of the left lower lobe (Fig. 1). Spirometry showed a severe obstructive pattern and the diffusing capacity of carbon monoxide was 35% (Table 1). Blood gas analyses

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Fig. 1 Preoperative computed tomography

Table 1 Comparison between spirometry and lung scintigraphy parameters before and 3 months after surgery

Variable	Preoperative	Postoperative
FEV ₁ L (%)	1.18 (28)	2.17 (52)
RV L (%)	1.6 (83)	2.30 (121)
TLC L (%)	3.94 (55)	6.64 (92)
FEV1/FVC	53.6	52.5
DLCO ml/min (%)	11.8 (35)	15.9 (46)
Perfusion right lung	92%	70%
Ventilation right lung	96%	75%
Perfusion left lung	8%	30%
Ventilation left lung	4%	25%

FEV1 forced expiratory volume in 1 s, *RV* residual volume, *TLC* total lung capacity, *FVC* forced vital capacity, *DLCO* diffusion of carbon monoxide

showed a pH of 7.42, PCO₂ of 44 mmHg, PO₂ of 81 mmHg. The echocardiographic study excluded signs of pulmonary arterial hypertension. Ventilation/perfusion scintigraphy reported on the left side a ratio of 4/8% and the right side 96/92%. Obviously, lung transplantation was not indicated at this time, and the patient was scheduled for giant bullae resection on the left side. Pre-emptive analgesia was performed using acetaminophen and ketorolac and the patient received preoperative dexamethasone as anti-emetic. The surgery was conducted in blended anaesthesia. The epidural T5/T6 catheter was positioned and the patient was monitored with invasive arterial blood pressure, continuous ECG, pulse oximetry, end-tidal CO₂ and bi-spectral index. The patient was intubated with a double-lumen tracheal tube then a central vein catheter was placed in the right jugular vein. The left internal jugular vein was cannulated under ultrasound guidance with a 13.5 fr double-lumen catheter (Joline; GmbH&Co, KG, Hechingen, Germany). The patient was placed in right lateral decubitus, just before skin incision the dual lumen catheter was connected to Pro-LUNG[®] system (Ester S.P.A. Pero, MI, Italy) for CO₂ removal after a previous heparin bolus 30 UI/kg followed by 18 IU/kg per hour maintenance infusion. The activated clotting time was maintained between 160 and 200 s (Video 1). Technical specification of this device are shown in Fig. 2. We ventilated the patient with pressure controlled ventilation (controlled pressure of 14 mBar; respiratory rate of from 14 up to 16/min), fraction of inspired oxygen (FiO₂) of 70% to achieve a TV of 4 ml/kg. The first blood gas analysis before Pro-Lung perfusion during one lung ventilation (OLV) was pH 7.29; pCO₂ 60.9 mmHg; pO₂ 165 mmHg, Lactate 0.76. After the introduction of Pro-Lung system (Digital VCO₂ 70 ml/min, air-flow 15 L/min 100% oxygen and blood pump flow 350 ml/min), we reached the normalization of the blood-gas parameters (Fig. 3), we decreased the respiratory-rate to 10/min and we gradually adjusted the ProLung air and blood flows as showed in Fig. 4. We chose a restrictive fluid management with crystalloids keeping an equal fluid balance. Video-assisted thoracic surgery with 3-portal approach was used to perform bullectomy. The thoracoscope port was placed at the eighth intercostal space along the mid axillary line the other two operative ports were placed, respectively, in the sixth intercostal space under the tip of the scapula and in the fourth intercostal space between the mid and anterior axillary line. We used a 30° 10 mm 3D-telescope. The main bulla was opened with cautery and deflated to make possible the surgical instruments movement inside the chest. The lung was then gently inflated to understand the boundary line between the normal parenchyma and the neck of the bulla, also evaluating the capacity for re-expansion of the chronically compressed parenchyma. The neck of the giant bulla was identified at the level of the lingular segment, taking care to place the staple line on healthy lung tissue the bulla

Fig. 2 Intraoperative view of the Pro-Lung system. The device is a venous-venous system connected to the patient with a dual lumen catheter (13.5 Fr) placed in the internal jugular vein. The blood flow is driven by a non-occlusive roller pump (0–450 mL/min) (red arrow) through a Polymethylpentene oxygenator with 1.8 m² of surface area (green-arrow) connected to a gas flow control unit (Pro-Lung Meter) delivering 100% oxygen in a range between 0 and 15 l/min (blue-arrow). The Pro-Lung meter provides real-time information about the oxygen flow (L/min), the air temperature (°C) and the amount of removed CO₂ (mL/min). The central screen of the device is used to monitor the blood flow and the inlet and outlet pressure through the catheter and to set the treatment (yellow-arrow). The circuit and the oxygenator are approved for 5 days of treatment. Continuous infusion of heparin was delivered by a 50 ml syringe pump integrated in the circuit

was excised. After inflating the left lung we identified other major bullae thus, further wedge resections were performed on the apical segment of the lower lobe and on the apico-posterior segment of the upper left lobe removing other huge bullae (Video 1). At the end of the intervention after careful checking for bleeding or important air-leak two 28 fr chest drains were placed through inferior thoracoscopic accesses, the third utility incision was closed. The operation time was 178 min and postoperative blood loss until drainage removal were 260 ml. At the end of surgery, considered the clinical respiratory stability and the good blood gas parameters, we reversed the rocuronium-induced neuromuscular block with intra-venous administration of sugammadex and, after a successful ventilator weaning, we extubated the patient in the

operating theater. When the patient was completely awake, the gas flow through the Pro-Lung system was gradually reduced and when blood gas check showed a normal pH with acceptable PCO₂ level the pump flow was stopped and the device disconnected from the jugular catheter (Figs. 3, 4). The first blood gas parameters, after the ECCO₂-R treatment, were pH 7.35, pCO₂ 51 mmHg, pO₂ 81.2 mmHg, lactate 1.13 mmol/L. We transferred the patient to the ICU where he remained for the first 12 h after the procedure for post-operative monitoring. He received post-operative analgesia with epidural ropivacaine 0.125% and he remained in spontaneous breathing with 2 l/min oxygen with normal blood gas parameters (Fig. 3). On post-operative day one the patient was transferred to the regular ward, the chest tube was removed on post-operative day four and discharged in optimal clinical condition after 9 days from the operation. Three months later the patient underwent spirometry-test and lung scintigraphy that showed a clear improvement when compared with the preoperative values (Table 1; Fig. 5).

Discussion

The use of ECCO₂-R devices has been extensively reported in literature as an advanced treatment for acute or chronic hypercapnic respiratory insufficiency [6]. In thoracic surgery the main application of ECCO₂-R devices is well documented as a bridge to lung transplantation [5]. Just recently some case reports described their application during tracheal surgery, residual lung surgery after pneumonectomy and to achieve ultra-protective single lung ventilation in high risk patients during thoracic surgery procedures [7–9]. Bullectomy for evanishing lung syndrome is today a validated option to improve respiratory function, quality of life and to delay the need for lung transplantation in very selected patients [2, 3]. The patient we describe was evaluated and scheduled for lung transplantation in another institution without considering that removing the left giant bullae could reduce thorax hyperinflation, increases the elastic recoil of the chronically compressed healthy lung tissue and improve the global muscle strength and normalize the diaphragmatic function [2]. After a careful preoperative evaluation with spirometry-test, pulmonary scintigraphy, 6-min walking test, echocardiography, computed tomography we decide to schedule the patient for left lung giant bullectomy. Anesthetic management of this kind of patient is the most critical point of the procedure. Indeed, it is mandatory to avoid aggressive ventilation of the single lung which has to be ventilated during surgery, otherwise it can result in dynamic pulmonary hyperinflation, alveolar barotrauma, cardiovascular instability, pneumothorax and chronic ventilator dependency [4, 8]. A safe single lung ventilation

Fig. 3 These two graphs show the variations of PCO₂ (a) and PH (b), before, during and after Pro-Lung treatment. *OLV* one lung ventilation, *DLT* double lung ventilation, *SB* spontaneous breath, *ICU* intensive care unit

should follow the principle of protective or even ultra-protective ventilation that consist in low or very low TV, low respiratory rate, long expiratory time and the lower as possible inspired oxygen fraction [10]. Unfortunately, in patients with vanishing lung syndrome, intraoperative

protective ventilation could lead to severe hypercapnia with respiratory acidosis, increases in pulmonary vascular resistance and right ventricular stress, hypotension and myocardial depression [4, 6, 8, 10]. Moreover, early extubation at the end of surgery is mandatory to prevent

Fig. 4 These four graphs reported all the parameters recorded directly by the Pro-Lung system that are available for download at the end of treatment. It is possible to have a continuous assessment of drop pres-

sure (a), inlet and outlet catheter pressure (a), the air-flow through the oxygenator (b), the blood flow through the pump (c) and the VCO₂ (volume of CO₂ removed by the membrane lung during treatment) (d)

hyperinflation of the residual bullae, especially in the non-operated lung, and to avoid staple line disruption with following prolonged air leak [2, 3, 7]. Obviously, early extubation is not possible in an hypercapnic patient. In our case the first blood gas analysis just few minutes after OLV showed hypercapnia with respiratory acidosis. To deal with this problem we planned the procedure predicting the intraoperative support of the Pro-LUNG system to guarantee a protective ventilation setting. In our experience, we already used this device in intensive care unit with very good results during hypercapnic respiratory failure mainly for acute respiratory distress syndrome or after lung transplantation. Indeed, this system is very simple to use and requires a small intravascular catheter (13.5 fr) that could be positioned safely with echography guidance. The 1.8 m² Polymethylpentene membrane lung is very effective to remove CO₂ with low blood flow between 300 and 450 ml and is guarantee for at least 5 days of continuous therapy with minimal anticoagulation that is important to minimize the intraoperative and post-operative bleeding risk. The possibility to monitor the amount of CO₂ removed by the filter in real-time with the ProLung-Meter

System is also very useful (Fig. 2). In our case, as reported in the Fig. 3, the CO₂ level was very effectively controlled during all the procedure, giving us the opportunity to extubate the patient safely immediately at the end of surgery, controlling the CO₂ level during recovery from anesthesia. The ProLung blood flow was stopped and the circuits disconnected only after the stabilization of the respiratory parameters, leaving the possibility to prolong the treatment in intensive care units in case of necessity.

Conclusions

In selected patients VLS bullectomy is an effective treatment to improve the clinical condition. Intraoperative management of ventilation is the most critical part of the operative planning. The use of ECCO₂-R device should be considered to achieve protective or ultra-protective ventilator strategies to reduce intraoperative and postoperative complications. Further studies with a more consistent population of patients is required to confirm our experience.

Fig. 5 Chest X-Ray and lung scintigraphy before (a, b) and after surgery (c, d)

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Compliance with ethical standards

Conflict of interest None.

Informed consent Written informed consent was obtained from the patient for publication of this manuscript and any accompanying images.

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