Clinical Reports

Temporary extracorporeal membrane oxygenation in the treatment of acute traumatic lung injury

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Purpose: To report two cases of acute life-threatening traumatic lung injury, who required temporary extracorporeal veno-venous membrane oxygenation (ECMO), and airlifting to a level I trauma centre.

Clinical features: The first patient suffered a severe motor vehicle accident with prolonged entrapment in the wreckage. After extrication, tracheal intubation, and fluid resuscitation, respiratory therapy failed to result in sufficient ventilation and oxygenation within the first hours after trauma due to severe lung contusion and intraparenychmal bleeding.

The second patient was hit by a falling tree and suffered isolated blunt chest trauma. Due to pulmonary contusions and tracheal rupture, subsequent ventilation management was limited by extensive mediastinal emphysema. Both patients were airlifted to a University Hospital and placed on ECMO for four and six days without complications, respectively. After emergency surgery and 21 and 26 days intensive care treatment, both patients were transferred to a general ward, and discharged from the hospital with full recovery.

Conclusion: These cases demonstrate the role of ECMO in the treatment of traumatic respiratory failure. If ventilatory support strategies fail due to severe lung or airway injury, ECMO may be an option for the temporary management of gas exchange in trauma patients.

Objectif : Rapporter deux cas d'atteinte pulmonaire traumatique, mettant la vie en danger, qui ont nécessité une oxygénation extracorporelle (OEC) veino-veineuse et un transport aérien vers un centre de traumatologie de premier niveau.

Aspects cliniques : Le premier patient a été victime d'un sévère accident d'automobile où il est resté coincé pendant une longue période. Après avoir été dégagé, on a procédé à une intubation endotrachéale et à une réanimation volémique, mais la thérapie respiratoire n'a pu fournir une ventilation et une oxygénation suffisantes pendant les premières heures qui ont suivi le traumatisme à cause des contusions pulmonaires sévères et du saignement intraparenchymateux. Le second patient a été blessé par la chute d'un arbre et a subi un traumatisme thoracique isolé. La présence de contusions pulmonaires et d'une rupture de la trachée a limité le traitement subséquent par ventilation en causant un emphysème médiastinal important. Les deux patients ont été transportés par avion vers un hôpital universitaire et placés sous OEC pendant quatre et six jours respectivement et ce, sans complication. Suivant une chirurgie d'urgence et 21 et 26 jours de traitement à l'unité des soins intensifs, les deux patients ont été déplacés à l'unité des soins généraux et ils ont quitté l'hôpital complètement rétablis.

Conclusion : Ces cas démontrent le rôle de l'OEC dans le traitement d'une défaillance respiratoire traumatique. Si les stratégies de soutien respiratoire ne réussissent pas à cause de lésion sévère des poumons ou des voies aériennes, l'OEC peut se présenter comme un choix de traitement temporaire des échanges gazeux chez les patients victime d'un traumatisme.

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FAILURE of respiratory support strategies after severe traumatic lung injury may be caused by haemo-pneumothorax, laceration of the airway including tracheal or bronchial disruption, and extensive pulmonary contusion; especially when associated with intraparenchymal bleeding. Although some of these life-threatening injuries can be treated surgically, maintenance of sufficient ventilation and oxygenation may be a fundamental problem before or even after surgery. Accordingly, employment of veno-venous extracorporeal membrane oxygenation (ECMO) may be an important intervention to treat refractory hypoxia and/or hypercarbia. In general, this technique is available on a regular basis mainly in hospitals with large intensive care units and the capability of cardiac surgery; therefore rendering this technology readily available mainly in trauma centres.

Patients requiring ECMO may need rapid transport from small hospitals or accident sites to a level 1 trauma centre. Therefore, despite limited possibilities of respiratory management during an airlift, and the incoherent risk of barotrauma-mediated further deterioration, helicopter transport may be indicated. In this report, we describe the case of two patients with life-threatening respiratory failure immediately after trauma, and subsequent helicopter transport to a trauma centre. Immediately after hospital admission, both patients were treated successfully with ECMO, which was maintained without complications until respiratory recovery.

Case #1

A 29-yr-old man suffered a motor vehicle accident at night on the highway. Although the emergency medical service was dispatched immediately, it took 20 min until an emergency physician arrived at the scene, and additional 60 min until extrication of the patient from the wrecked car. During the rescue operation, the patient was conscious, but showed signs of respiratory distress. Adequate circulation was maintained by aggressive fluid management. After extrication and induction of anaesthesia, tracheal intubation was performed, and a left-sided chest tube was inserted because the initial impression strongly suggested a haemo-pneumothorax. Approximately two hours after the accident, the patient was transported to the hospital which was located closest to the accident scene.

After admission, chest x-ray revealed a left-sided tension haemo-pneumothorax, multiple rib fractures, severe contusions of both lungs, as well as a fracture of the clavicle and a minor hip fracture. The tip of the chest tube could be located in a dorso-apical position,

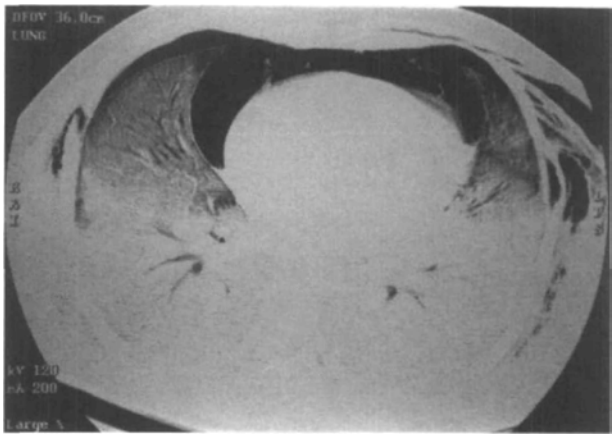

FIGURE 1 Case report #1: CT scan after admission to a major trauma centre. Homogenous opacification of both lungs with ventro-dorsal gradient representing acute lung-injury combined with pneumothorax and pneumomediastinum on both sides.

surrounded by haematoma and atelectatic areas of the lung. Two additional chest tubes were then inserted and advanced to a more ventral position. Fluids as well as packed red cells were rapidly infused up to a level of 10 $g \cdot dL^{-1}$ haemoglobin to maintain adequate circulation and tissue perfusion. Results of arterial blood gas analysis during the next hours during continuous positive pressure ventilation (inversed ratio ventilation 2:1; pressure controlled ventilation; P_{max} 32 cm H_2O; FIO_2 1.0; f 20; V_T 400 mL; PEEP 10 cm H_2O; mean airway pressure 25 cm H_2O) are given in Table I.

Five hours after admission, helicopter transfer to a trauma centre (distance, 75 km) was arranged for further treatment. Immediately after admission to the trauma centre emergency room, arterial blood gas analysis revealed severe respiratory failure. Percutaneous ECMO was established, and resulted in an instantaneous improvement in oxygenation and ventilation. The extracorporeal circuit consisted of a centrifugal pump (Biopump, Biomedicus, Eden Prairie, MN, USA), and a hollow fibre oxygenator (Maxima, Medtronic Blood System, Anaheim, CA, USA) with an integrated heat exchanger; the entire extracorporeal system (Medtronic, Kerkrade, Netherlands) was heparin coated.

After diagnostic radiology imaging, the patient was transferred to the intensive care unit (ICU) for further therapy. Table II shows the results of blood gas analysis under partial ECMO (~40% of cardiac output), and biphasic positive airway pressure (pressure-ratio 35/20 mbar, time ratio 1.2/1.2 sec). Inspiratory oxygen fraction was reduced in the next 12 hr from 1.0 to 0.5. The whole blood activated clotting time was kept

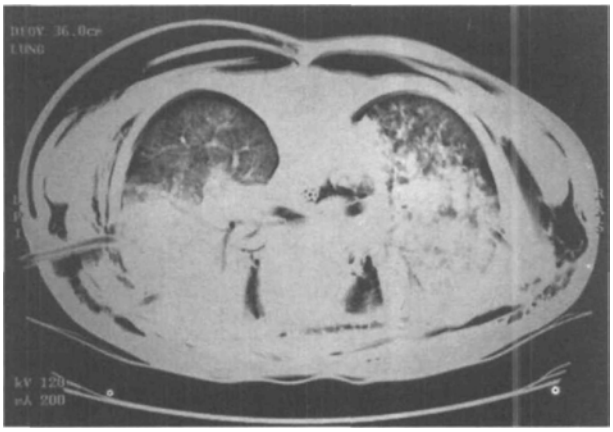

FIGURE 2 Case report #2: CT of the thorax in prone position demonstrates extensive traumatic injury of both lungs with homogenous lung haemorrhage ventrally as well as pneumothorax and soft tissue emphysema

between 120 - 140 sec with an infusion of 200 - 700 IU·hr^{-1} heparin. Subsequently, diagnostic imaging revealed that signs of severe pulmonary contusion, emphysema, and adult respiratory distress syndrome (Figure 1) diminished within the following days. During four days of ECMO support, no problems or complications occurred, and ECMO was stopped. After 15 additional days of ventilation, extubation was successful; the patient was discharged from the ICU five days later, and discharged subsequently from the hospital with full recovery.

Case #2

When attending his father during work in a forest, a 12 year-old boy suffered a severe blunt thoracic trauma by a falling tree. After an initial episode of unconsciousness, he was awake, but suffered respiratory distress. Because of the remote location, it took 35 min until a local physician arrived at the scene, who was followed shortly thereafter by a physician-staffed emergency medical service helicopter. Rapidly expanding surgical emphysema, comprising the entire trunk and neck, made airway management extremely difficult. However, orotracheal intubation with a 6.0 mm tube was successful, and a chest tube was inserted on the right side because of unequal breath sounds in the physical examination.

Subsequently, ventilation deteriorated; this was reflected by high peak inspiratory airway pressure even with small tidal volumes. This status influenced the decision to airlift the patient to the nearest county hospital (flight time, 10 min) for further stabilization and diagnostic imaging. After optimizing the position of the endotracheal and chest tubes in the county hospital emergency room, the patient was prepared for helicopter transport to a trauma centre. During the subsequent 30 min flight, ventilation was performed with a bag-valve device instead of with an automatic transport ventilator, but remained difficult.

Diagnostic imaging in the trauma centre emergency room revealed a ventral pneumothorax as well as parenchymal lung contusions on both sides (Figure 2). Additional chest tubes were inserted, and the patient was transferred to the ICU. Despite biphasic positive airway pressure ventilation (pressure-ratio 35/10 mbar; inversed time-ratio 2.0/0.6 sec; FiO_2 1.0), oxygenation and ventilation deteriorated within the next hours (lowest PaO_2, 50 mm Hg). Approximately 24 hr after admission to the trauma centre, tracheal rupture was diagnosed by endoscopy. The patient was then placed immediately on veno-venous ECMO; a right-sided thoracotomy was performed, and a rupture spreading from the lateral wall of the distal trachea into the right main bronchus, was sutured over 4 cm.

An ECMO flow of 3.3-3.5 L·min, reflecting ~50% of cardiac output, was continued for six additional days, during which no problems or complications occurred. Anticoagulation was closely monitored and an ACT of 120-150 sec was maintained with a heparin infusion of 150-1000 IU·hr^{-1}. Diagnostic imaging revealed an improvement, and ECMO was stopped without resulting changes in oxygenation and ventilation. Despite persisting intraparenchymal haematomas on both sides, extubation was successful after 14 days of intensive care therapy; the patient was transferred to a general ward 26 days after the accident, and left the hospital with full recovery.

Discussion

Severe thoracic trauma may result in intractable acute respiratory failure caused by lung or airway injury. In both cases described in this report, patients suffering from blunt thoracic trauma, received comprehensive pre-hospital treatment including early intubation, insertion of chest tubes and cardio-circulatory stabilization. Nevertheless, further respiratory support strategies failed due to severe pulmonary contusion, and tracheobronchial rupture with extensive mediastinal emphysema, respectively. Life threatening hypoxaemia, and hypercarbia immediately after admission to the major trauma centre were the fast entrance criteria for the establishment of ECMO. Although both patients had pulmonary contusions with intraparenchymal bleeding and one patient needed surgery, there were no bleeding complications or evidence for further organ failure during ECMO, which was maintained for four, and six days, respectively.

TABLE I Case #1: Arterial blood gas analysis after admission, two hours after the accident, immediately after helicopter transport to the emergency room of a trauma centre, and after ICU admission.
Pressure controlled ventilation (IRV, V_T 400 mL, f 20, PEEP 10 cm H_2O, FiO_2 1.0)

Time after admission	*pH*	*$PaCO_2$ (mmHg)*	*PaO_2 (mmHg)*	*HCO_3 (mmol) / BE*	*SaO_2 (%)*
30 min	7.11	82.8	72.1	21.3 / -3.5	89.7
4 hr 45 min	7.21	58.9	34.4	23.5 / - 4.9	69.4
Helicopter Transport - total transport time 1 hr 10 min (30 min flight)					
Admission ER	7.0	76	20.9		45
ECMO Bloodflow, 4 L·min^{-1}, BIPAP Ventilation (25/20 mbar, 1.2/1.2 sec, FiO_2 1.0)					
Admission ICU	7.38	29.7	100	17.5 / -6.0	97.6

ER indicates Emergency Room; ICU, Intensive Care Unit; BIPAP, biphasic positive airway pressure; ECMO, extracorporeal membrane oxygenation.

TABLE II Arterial blood gases showing improvement of pulmonary function in patient 1 during ECMO support in the intensive care unit.

Days in ICU	pH	PCO_2 (mm Hg)	PO_2 (mm Hg)	HCO_3 (mmol) / BE	SaO_2 (%)
2	7.49	28.3	205.8	21.7 / 0	99.5
3	7.46	32.0	207.8	22.8 / 0	99.5
BIPAP (30/20 mbar, 1.5/1.5 sec, FiO_2 0.4)					
4	7.42	32.6	149	21.6 / -1.8	99
ECMO stop - BIPAP (27/17 mbar, 1.3/1.4 sec, FiO_2 0.4)					
5	7.30	49.6	129.7	24.3 / -1.8	98.2

ICU indicates intensive care unit; BIPAP, biphasic positive airway pressure; ECMO, extracorporeal membrane oxygenation.

Approximately 5% of mortality in trauma victims is directly caused by thoracic trauma.[1] On the other hand, respiratory failure has the highest incidence (30-50%) among post-traumatic organ failure, often resulting in intractable, progressive adult respiratory distress syndrome (ARDS); and therefore, an increasing mortality in trauma. Accordingly, direct parenchymal lung damage due to thoracic trauma and consecutive morphological changes through an inflammatory systemic process are the two most important pathophysiological causes of respiratory failure.[1]

As even the most advanced ventilatory support strategies, including inversed ratio ventilation (IRV), individual adjustment of positive end-expiratory pressure (PEEP), or pressure controlled IRV with permissive hypercarbia might fail to maintain adequate oxygenation in severe ARDS, the need for extracorporeal techniques of gas exchange will become evident.

The first successful use of ECMO in adults for acute post-traumatic respiratory failure was reported by Hill *et al.* in 1972.[2] After initial disappointments, it was temporarily abandoned. A prospective trial of ECMO and conventional management in adult respiratory distress syndrome, sponsored by the US National Heart and Lung Institute in 1979,[3] demonstrated an equivalent 90% mortality. In this setting, time of mechanical ventilation before initiation of ECMO averaged 9.6 days, and ventilation was maintained during ECMO using high peak inspiratory airway pressure. Accordingly, the ECMO group showed increased survival rates only in the initial days (2-11) of treatment.

In 1986, Gattenoni *et al.*[4] presented the results of a study that suggested to reconsider the efficacy of ECMO in a setting quite similar to the US National Institute of Health trial. Eliminating carbon dioxide with ECMO, their respiratory therapy differed from the US National Institute of Health protocol, avoiding high peak inspiratory airway pressure, and high oxygen concentrations; which subsequently resulted in a survival rate of 48%. In further publications of survival rates of patients suffering from acute respiratory failure after trauma, survival rates ranged between 5-63%.[5,6]

In 1997, Lewandowski *et al.*[7] presented a clinical approach to the management of patients with ARDS. Following an algorithm including ECMO, an overall survival rate of 55-75% in the ECMO group was achieved. Admission criteria included the diagnosis of ARDS and a preceding respiratory therapy >48 hr

TABLE III The Deadly Dozen Thoracic Injuries (Caroline *et al.*, 1995)

Immediately life-threatening chest injuries that must be detected and treated during initial management at the scene
1. Airway obstruction
2. Open pneumothorax
3. Tension pneumothorax
4. Massive hemothorax
5. Flail chest
6. Cardiac tamponade
Potentially lethal chest injuries that may be identified at the scene or in the hospital
7. Thoracic aortic disruption
8. Bronchial disruption
9. Myocardial contusion
10. Diaphragmatic tear
11. Esophageal tear
12. Pulmonary contusion

before transfer to the ICU. After admission, patients were treated with ECMO when rapid entry criteria were matched within the first two hours. Keys to success of ECMO may be early initiation of ECMO,[5,6,8] the time on ECMO, which should not exceed 15 days,[8] and careful monitoring of coagulation during ECMO using a heparin bonded circuit.[6,9]

Both of our patients were treated by ECMO within 24 hr of suffering thoracic injury. In the first case, rapid entry criteria were matched with PaO_2/FiO_2 <50 at PEEP > 10 cm H_2O and FiO_2 1.0. The underlying pattern of an early respiratory distress syndrome could be rapidly improved by ventilatory support, but needed ECMO temporarily to avoid prolonged hypoxia. The second patient needed ECMO for surgical intervention and furthermore, to gain time for recovery from pulmonary contusions. Other possible strategies of airway management such as fiberoptic positioning of a double-lumen tube was contraindicated because of the extend of the tracheal rupture and the diameter of the juvenile airway. In both cases, ECMO could be limited to no more than six days.

Bleeding disorders are the most important complications when using ECMO. Systemic anticoagulation with a heparin dose that is sufficient to achieve whole blood activated clotting times between 160-180 sec, may be followed by bleeding complications in 68 - 75%.[5,6] Platelet dysfunction due to cell trauma, hyperfibrinolysis, and the degree of anticoagulation are typical causes of coagulopathy during ECMO.[10] In 1995, Perchinsky *et al.*[9] found a close relationship between the coagulation status of massively injured patients undergoing ECMO and their outcome. In a study of Lewandowski *et al.*,[7] the complication rate was mainly influenced by technical problems, when 22 of 27 complications (occurring during 27,137 h of ECMO) were caused by malfunction of the cannula or parts of the ECMO equipment.

In both cases, no bleeding, thromboembolic, or technical complications occurred; which was mainly achieved by permanently monitoring anticoagulation. A whole blood activated clotting time level of 120-140, which is less than in other ECMO protocols, provided a sufficient function of extracorporeal circulation. This was maintained by infusion of 200-1000 $IU \cdot hr^{-1}$ heparin.

Obviously the question arises, whether different strategies of pre-hospital management or a more aggressive use of chest tubes might have been beneficial. The half of a "Deadly Dozen" of thoracic injuries (Table III) must be identified and managed at the accident site by the emergency medical service.[11] Early tracheal intubation and ventilation are the most important procedures in reducing mortality in trauma,[1,12] furthermore, an aggressive policy of decompression of a pneumothorax may further reduce the number of avoidable deaths.[12,13] According to Powell *et al.*,[14] our patients can be classified as "risk level 1", indicating a situation in which a delayed transport to a trauma centre, or a delay in administering major interventions, would threaten survival fundamentally. Although both bag-valve and automatic transport ventilators represent adequate ventilatory devices in the emergency medical service,[15] both cases demonstrate that advanced ventilatory support strategies should be maintained during transport. Despite a possible improvement in respiratory therapy technology, air transport bears the risk of barotrauma. For example, even if a chest tube is in correct position, there still may be the risk of a tension pneumothorax. A more aggressive use of chest tubes in the early phase of treatment might have been helpful to prevent the development of tension pneumothorax.

After admission to the trauma centre, both patients were endangered by critical hypoxemia, requiring immediate improvement of gas exchange. Therefore, ECMO was initiated, resulting in dramatic improvement of oxygenation and CO_2 removal. In 1992, Levy *et al.*[16] proposed a more liberal application of ECMO in adult patients. When critically assessing possible complications, ECMO may be considered a last resort therapy for acute lung failure. The time course of respiratory deterioration after thoracic trauma can be very short, and early identification of patients who require advanced treatment in a trauma centre including the option for ECMO, may be the key to success

and subsequent increased survival rates. Accordingly, all criteria for a good ECMO outcome were matched in these two patients: early initiation, short duration, and undisturbed external blood flow due to a strict anticoagulation management.

In conclusion, these two cases describe a benefit of ECMO therapy after severe thoracic trauma with respiratory failure. Further randomized trials should examine whether an early initiation of ECMO may result in lower mortality after blunt trauma, especially when managing thoracic injury.

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