Research article

Extracorporeal lung support in patients with spinal cord injury: Single center experience

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Objective: Trauma-related spinal cord injury (SCI) leads to a loss of motor, sensory and vegetative functions and is disproportionately associated with respiratory complications. SCI has a significant impact on respiratory muscle function and can lead to respiratory dysfunction or severe lung failure.

Participants: Between 2008 and 2014, 7 patients with severe lung failure following SCI received veno-venous extracorporeal membrane oxygenation (ECMO) $n = 5$ and interventional lung assist (iLA) $n = 2$.

Results: The median duration of extracorporeal lung support was 8 (5.7–17.6) days. All 5 of the ECMO-supported patients were successfully weaned, and one of the two patients treated with iLA was weaned from the device. The median intensive care unit (ICU) stay was 35 (8.5–44.5) days. The mean hospital stay was 81 (8.5–120.7) days, and the average ventilation time was 817 (206–1,225) hours. Five (71.4%) of the 7 patients were discharged from the ICU and hospital.

Conclusions: In patients with SCI, serious complications include microatelectasis, infection, ventilation-perfusion mismatching and aspiration (special case: salt-water aspiration after jumping into shallow water). In patients with SCI with post-traumatic lung failure, ECMO is a feasible and life-saving procedure. After surviving spinal shock, a long rehabilitation period with intensive follow-up in specialized centers is required.

Keywords: Extracorporeal life support (ECLS), Extracorporeal membrane oxygenation (ECMO), Major trauma, Spinal cord injury

Introduction

Trauma-related spinal cord injury (SCI) leads to a loss of motor, sensory and vegetative functions¹ and is associated with potentially devastating respiratory complications.² In addition to the initial trauma-related damage to lung tissue, SCI can cause major respiratory complications, such as atelectasis, pneumonia, reduced vital capacity and respiratory failure.³ The relationship between SCI and an increased risk of respiratory failure is well-documented. In a manner that depends on the SCI level, more than 65% of patients with SCI develop respiratory problems, and more than 60% of SCI patients in average require invasive mechanical ventilation.^{4–6} The level of SCI influences the need for mechanical ventilation. The mechanical ventilation itself can have negative consequences for the lungs. Ventilation with higher tidal volumes (>6 ml/kg) causes further damage to the lungs (ventilation-

induced lung injury = VILI) characterized by a pro-inflammatory response (biotrauma) and reduced lung compliance. VILI has a negative impact on the survival of patients undergoing mechanical ventilation.⁷

If lung-protective ventilation cannot be conducted, extracorporeal lung support (iLA/ECMO) can provide systemic tissue oxygenation and decarboxylation while avoiding ventilator-associated barotrauma to the lung tissue. Moreover, ECMO can be used as a salvage therapy for patients with acute respiratory distress syndrome (ARDS) and refractory hypoxia.⁸ Venovenous ECMO primarily provides gas exchange to replace or support lung function. Blood is drained from the inferior vena cava via a femoral venous cannula or from the superior vena cava via an internal jugular venous cannula. The blood is pumped via the oxygenator back into the venous system through the internal jugular vein or through the second femoral venous cannula. Alternatively, a dual-lumen cannula can be employed for simultaneous venous drainage and return. Venovenous ECMO can provide partial to

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full extracorporeal pulmonary support with blood flow up to 6 L/min.

Pumpless systems, which use the arteriovenous pressure gradient of the patient to create a shunt from the artery to the vein (interventional lung assist (iLA); NovaLung, Hechingen, Germany), facilitate extracorporeal carbon dioxide removal and can support mechanical ventilation by enabling a low tidal volume and a reduced inspiratory plateau pressure.¹⁰ Additionally, initial improvements in oxygenation with high-frequency oscillatory ventilation (HFOV) appear to be a potential alternative to conventional ventilation.⁹ However, HFOV is not advantageous compared with conventional ventilation.^{11,12}

ECMO is now frequently used in patients with bleeding risk, and is no longer considered a true contraindication, but rather a situation that may modify the way ECMO is used and the patients managed.

Here, we present the retrospective results from patients with tetraplegia and paraplegia who underwent post-traumatic lung failure treatment using extracorporeal lung support (ECMO and iLA). This report is the first documented case series of patients with SCI treated with extracorporeal devices prior to lung failure.

Methods

The surgical intensive care unit (ICU) has a capacity of 13 beds and more than 2,500 admissions per year. The University hospital provides trauma services and care for work-related injuries and includes a department for the treatment and rehabilitation of patients with SCI.

This retrospective, observational, single-center study included five patients with tetraplegia and two with paraplegia (6 male, 1 female) with SCI. The patients were treated between January 2008 and December 2014 at a level-one trauma center. The extracorporeal lung support methods included iLA and ECMO.

Privacy policy

All patients were assigned a consecutive number. The data were saved using only this code in an exported database in an SPSS (IBM Corp., Armonk, NY, USA) data sheet on an access-controlled computer. The data were evaluated, and only authorized personnel had access to the original data.

Setting

All patients with SCI, treated in the ICU, who presented with severe respiratory failure treated by ECMO or iLA were included in the study. The 7 patients with SCI were a subgroup (0.7%) of 981 trauma patients treated during this period in the ICU (Table 1). These patients

Table 1 Numbers of trauma patients treated in the surgical ICU within time period 2008–2014

	Total	Trauma patients treated with ECMO or iLA	Patients with SCI treated with ECMO or iLA
Number of patients	981	49	7
Injury severity score (mean)	19.1	33	32

SCI = spinal cord injury

experienced a traumatic SCI and developed severe post-traumatic lung failure. According to the American-European consensus conference criteria, all 7 patients developed ARDS.¹³

Four patients experienced high-energy impact road accidents, 2 patients fell from heights > 5 meters, and in one case, the exact circumstances of the accident remained unclear. Five of the seven patients suffered severe fractures of the cervical and the thoracic spine and presented with additional chest trauma with serial rib fractures, hemothorax and lung contusions (Table 2).

As long as mandatory ventilation was needed, all 7 patients were mechanically ventilated using a BIPAP-Mode (Biphasic Positive Airway Pressure) (Dräger Medical, Lübeck, Germany). According to the ARDS Network Study Group, the ventilation parameters were selected to ensure lung-protective ventilation.

Four patients required continuous renal replacement therapy (Ci-Ca CVVHD; Fresenius Medical Care, Bad Homburg, Deutschland) after initiating ECMO therapy due to acute renal failure. Four patients were stabilized prior to cannulation by spinal fusion. The mean time between trauma and extracorporeal lung support cannulation was 5.8 days (1–18 days).

Interventions

Cannulation

The indications for extracorporeal lung support (iLA/ECMO) was provided as follows:

- hypoxemia ($pO_2/FiO_2 < 200$ mmHg)
- tidal volume > 4–6 ml/kg ideal body weight,
- P_{insp} < 30 cm H₂O
- severe hypercapnia with increased pCO_2 if the pH < 7.2

The patients were failing in oxygenation and lung compliance. Additionally the increasing need for vasopressors (epinephrine > 1 mg/h) was the dynamic parameter to estimate the severity of the lung failure.

The target values for the iLA were severe hypercapnia with increased pCO_2 if the pH < 7.2. iLA provides only the extracorporeal CO₂ removal.

Table 2 Classification of the injuries

	Polytrauma	Chest trauma	Asia-Classification	Level of SCI	Cervical spine injury(ies)	Thoracic spine injury(ies)	Limb-fractures	Prior lung disease
Patient 1	x	x	A	TH3	Dens fracture (Anderson Type 3)	TH 3; TH 4 (AO-Type B3) TH 4; TH 5 (AO-Type A3)		
Patient 2	x	x	C	C6	Atlas fracture (Jefferson Type) Dens fracture (Anderson Type 3)	TH3 (AO-Type C1)		
Patient 3	—	—	B	C6	C6 (AO-Type C3)	—		
Patient 4	x	x	D	C6	C6 (AO-Type C1)	TH3 (AO-Type C1)		
Patient 5	x	—	B	C2	Dens fracture (Anderson Type 3) C 4; C 5 (AO-Type C2)	—		
Patient 6	x	x	A	TH2	—	TH2 (AO-Type C3)		
Patient 7	x	x	A	TH8	—	TH8 (AO-Type B2)		

Each cannulation was performed bedside percutaneously using the Seldinger technique. Heparin (5,000 IE) was administered intravenously before the cannulation.

The two patients treated with iLA were cannulated arteriovenously via the femoral artery (15-French cannula) and femoral vein (17-French).

Three patients were cannulated using dual lumen cannulas (31-French, Avalon, Maquet, Rastatt, Germany) via the right internal jugular vein. The remaining two patients were cannulated via the right internal jugular (21-French) and the femoral vein (25-French). For veno-venous ECMO treatment, CardioHelp (Maquet, Rastatt, Germany) was used.

Ventilator management and ECMO / iLA settings

Blood flow after initiating ECMO was 100–120 ml/kg body weight (BW)/minute. The flow was calibrated based on arterial blood gases according to the arterial partial pressure. The target oxygen partial pressure (pO₂) was 60 mmHg, and the target arterial oxygen saturation (SaO₂) was >90%.

Oxygen was the sweep gas, and the flow rates ranged from 1 to 15 liters per minute. The flow was adjusted according to the PaCO₂ and pH levels. A pH level greater than 7.2 was desired. An oxygen flush was performed 3 times in 24 hours on iLA (the oxygen flow rate was increased to 15 liters per minute).

After cannulation, to facilitate lung tissue healing, the tidal volume, minute ventilation, positive end-expiratory pressure and FiO₂ were decreased. To limit the potential risk for atelectasis, the positive end-expiratory pressure was not reduced to less than 10 cm of H₂O. Depending on the compliance of the respiratory system and the amount of the PEEP, the peak pressure

was chosen such that a tidal volume of 4 ml/kg of ideal body weight was strictly achieved. The maximum pressure limit was set to 30 cm of H₂O. Primarily as long as controlled ventilation was needed, all 7 patients were ventilated using a BIPAP-Mode. The main goal to maintain the ventilation and initiate weaning from the extracorporeal device and from the ventilator is to reduce the sedation targeted on Ramsay Score. With a target Ramsay score of 2, spontaneous breathing efforts with ventilatory support (CPAP-Mode) were allowed during ongoing ECMO therapy.

In 6 of 7 patients, a percutaneous tracheotomy was performed at the bedside after 9 ± 5.3 days in the ICU. One patient received a tracheostomy in the referral hospital before admission to the study ICU.

Anticoagulation

Assuming the patients experienced no increased risk of bleeding, patients cannulated with 2 single ECMO cannulas received 400 IU of unfractionated heparin per hour. Single lumen cannulas are heparin coated and the pTT targeted anticoagulation can be interrupted for limited time. In patients cannulated with uncoated, double lumen cannula, heparin dosage was calculated based on the partial thromboplastin time (pTT) had a target pTT of 50 seconds. Patients treated with iLA had a target pTT of 60–80 seconds. If heparinization failed (pTT does not rise adequately 6 hours after starting therapy), the patients received 1.000 IU of AT3. In addition to the heparin, the iLA-treated patients received 100 mg acetylsalicylic acid daily. The ECMO and iLA system was checked daily by the perfusionist for leaks and clots. Platelets were substituted to maintain a platelet count greater than 50,000 per mL.

Decannulation

After successful recovery of the lung tissue and improvement in lung function (according to the Murray lung score¹⁴), [2.11] the extracorporeal blood flow was reduced stepwise to 2.0 L/minute prior to arterial pO₂. The sweep gas was reduced prior to pCO₂ and pH. The specific criteria used for weaning are the lung compliance, radiography and the level of SCI. The sweep gas was then removed. If the arterial gas exchange parameters remained stable, then the cannulas and the oxygenator were removed.

Results

Five patients received veno-venous ECMO, and two patients were cannulated for iLA. All five patients (100%) were successfully weaned from ECMO, and one patient was weaned from the iLA. The median length of stay (LOS) in the ICU was 35 days, and the mean hospital LOS was 81 days, including the early phase of rehabilitation and further ventilation weaning. The mean ventilation duration was 817 hours (median, approximately 34 days) (Table 3). Physiotherapy has been started immediately and decreased prior to the general condition of the patient. Tetraplegic patients were weaned using support from a mobile home ventilator during in-hospital rehabilitation outside of the ICU.

Complications

No bleeding complications occurred. Dislocation of the venous cannula (iLA) during prone positioning was one severe complication with lethal outcome. The second complication was oxygenator clotting and thrombosis around the dual lumen cannula, which occurred in a patient who was almost completely weaned from ECMO. In this case, the cannula removal was performed surgically.

Survival

In comparison with all trauma patients who received ECMO or iLA, the SCI group required longer ventilation periods (567 vs. 817 ventilation hours) due to the pathophysiology of the tetraplegic injury and experienced a longer in-hospital LOS (46.7 vs. 81 days), which may be explained by the rehabilitation time required (Table 3).

In total, 6 (85%) of 7 SCI patients were weaned from the extracorporeal devices. This promising result demonstrates the potential for these methods as feasible treatments with good associated outcomes. One tetraplegic patient who presented with a lesion above the C4 segment had no potential for successful weaning from the mechanical ventilator based on the required life-long support for this patient from a mobile home ventilator. This patient did not provide consent for further therapy to treat ventilator-associated pneumonia and subsequently died.

The 71.4% survival rate indicates that extracorporeal devices are a feasible treatment option for SCI patients (Table 3). Today, patients have many rehabilitation options. Two of the five survivors participated in locomotor rehabilitation training using voluntary driven exoskeletons (HAL) and achieved very good functional outcomes.¹⁵

Discussion

In patients with SCI, serious complications include microatelectasis, infection, ventilation-perfusion mismatching and aspiration (special case: salt-water aspiration after jumping into shallow water). Post-traumatic lung failure is a combination between lung contusion, fluid overload and organ failure triggered by systemic inflammatory response syndrome.

Therapy for lung failure following trauma continues to be challenging due to the increased risk of bleeding complications. However, ECMO has yielded promising results in these patients.^{16–18} Experience with ECMO therapy for patients with SCI is limited. This report

Table 3 Comparison between ECMO-treated trauma patient group and ECMO-treated patients with SCI within time period 2008–2014; all values in median (range)

	Trauma patients treated with ECMO or iLA (n = 49)	Patients with SCI treated with ECMO or iLA (n = 7)
Age (years)	49.9 (16.6–86.2)	54 (19–66)
BMI	27.7 (20–37)	28 (21–36)
SAPS II Score	67 (32–101)	69 (48–79)
SAPS 3 Score (%)	63 (36–88)	58 (49–73)
ISS-Score	32 (4–66)	32 (16–50)
Duration of ventilation (hours)	567 (45–1,506)	817 (206–1,225)
Extracorporeal lung support (ECMO or iLA) duration (days)	9.2 (0.1–21.4)	8 (5.7–17.6)
Post-ECMO time in hospital (days)	29 (0–110.9)	64 (0–110.9)
Length of stay in ICU (days)	24 (4.8–197.6)	35 (8.5–44.5)
Hospital stay (days)	46.7 (4.8–126.6)	81 (8.5–120.7)
Survival at hospital discharge (%)	65.3%	71.4%

represents the first case series of patients with SCI and post-traumatic lung failure treated with extracorporeal devices. SCI has a significant impact on respiratory muscle function and can lead to respiratory dysfunction or severe lung failure. Serious complications include atelectasis, ventilator-associated pneumonia, infections and aspiration (special case: salt-water aspiration after jumping into shallow water).

According to the CESAR trial,¹⁹ a Murray score of at least 3 or a pH less than 7.2 with uncompensated hypercapnia is the criterion for using ECMO. In addition, the recommendations described by the REVA group are based on 3 parameters: acidosis, ventilator pressures and the Horowitz index. However, these recommendations are for patients with influenza-associated respiratory failure.²⁰

Although only a small number of cases were encountered over the period of this study, we achieved satisfactory results with ECMO therapy (71.4% survival). Despite the relatively long duration of mechanical ventilation and ECMO therapy, we achieved satisfactory results that were similar to those reported by Wagner *et al.*, who demonstrated that there was no link between a long duration of mechanical ventilation or extended ECMO therapy and survival.²¹

Conclusions

In patients with traumatic SCI and post-traumatic lung failure, extracorporeal lung support is a feasible and life-saving procedure. Even after surviving spinal shock, a long rehabilitation period with intensive follow-up in specialized centers is required.

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