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CURRENT TOPICS

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Extracorporeal circulation for acute respiratory failure

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Introduction

The management of acute respiratory distress syndrome (ARDS) is aimed at maintaining oxygenation and CO_2 removal while avoiding ventilator-induced lung injury related mainly to barotrauma, local and systemic effects of mediators release, and oxygenation toxicity. Current ventilatory management strategies include limitation of end-inspiratory pressure and tidal volume, inverse ratio ventilation, titration of PEEP by SvO_2, permissive hypercapnia, limitation of FiO_2, nitric oxide inhalation, and surfactant replacement. The integrated approach to critically ill patients entails the use of dehydration, control of infection, and possibly prone positioning.

Extracorporeal membrane oxygenation (ECMO) still can be proposed as an option in patients not responding to other forms of therapy. Clinical experience with the extracorporeal management of ARDS now extends well over 20 years; nevertheless, its application in adult and paediatric patients shows significantly less success than neonatal applications. Treatment of ARDS with ECMO can be life-saving but requires maximal use of intensive care resources over prolonged periods of time, resulting in high costs.

In spite of these treatments, the mortality of ARDS remains around 50%. The most important complications of ECMO are bleeding either from the vascular access or in vital organs (intracranial, gastrointestinal), mainly due to systemic anticoagulation, and hemolysis due to the effect of the blood pump. The goal of ECMO technological improvement, besides gas-exchange efficiency, should be to decrease the incidence of complications due to the activation of blood components from the circuit, the oxygenator, and the pump, reducing the blood-contacting surface and allowing a milder anticoagulation regime.

Kolla S, Award SS, et al (1997) Extracorporeal life support for 100 adult patients with severe respiratory failure. Ann Surg 226:544–566

This retrospective non-randomised trial enrolled 141 adult patients referred for severe respiratory failure from several institutions. All patients were treated with a standardised hypoxic respiratory failure protocol. One hundred patients were included in the extracorporeal life support (ECLS) group. The selection criteria for ECLS in 94 ARDS patients were: transpulmonary shunt more than 30% (or PaO_2/FiO_2 ratio less than 100), compliance less than 0.5 ml/cmH_2O/kg, mechanical ventilation for less than 5 days, and age less than 60 years. For the others six patients with hypercarbic respiratory failure, the inclusion criteria were an unresponsive status asthmaticus with a pH value below 7 and an end-inspiratory pressure over 45 mmHg. Vascular access, the extracorporeal life support circuit, management of the patient, the anticoagulation protocol, and the weaning criteria from the ECLS and the ventilator are well discussed; venovenous access was performed in 65 patients, venoarterial in 11 patients; in 24 patients the vascular access was changed at least once. The necessity to change from venovenous to venoarterial bypass was associated with fatal outcome: all seven

patients died. Out of 100 ECLS patients, 54 (54 %) survived to discharge. Among 11 pre-ECLS variables in the 94 patients with ARDS, a stepwise logistic regression to identify independent predictive factors of outcome revealed the following as the most important variables: (1) age, (2) PaO_2/FiO_2 ratio, and (3) pre-ECLS ventilator days. During ECLS the variables predictive of survival were: (1) bleeding in the site of cannulation and (2) serum creatinine below 1.5 mg/dl. No mechanical or technical complication was found as an independent predictor of survival.

Struber M, Haverich A (1999) Extracorporeal membrane oxygenation – new developments. Thorac Cardiovasc Surg 47 (Suppl):304–306

In this review paper, the authors emphasise a significant reduction of publications on CO_2 removal in recent years; on the other hand, classic extracorporeal membrane oxygenation remains a therapy for cardiopulmonary failure. Technical improvements have made the ECMO procedure safer and less invasive: complete surface heparinization of the whole circuit; servo controller to avoid negative pressure in the pump (roller or centrifugal); and the hollow-fibre oxygenator. Significant help for the management and weaning from ARDS stems from "cotherapy": permissive hypercapnia, pressure-controlled ventilation, kinetic therapy, and the use of nitric oxide. Surfactant replacement failed to prove effective. This cotherapy reduced the need for ECMO for lung failure: the last five patients referred for ECMO to the author's centre were successfully treated without extracorporeal circulation.

Ullrich R, Lorber C, et al (1999) Controlled airway pressure therapy, nitric oxide inhalation, prone position, and extracorporeal membrane oxygenation (ECMO) as components of an integrated approach to ARDS. Anesthesiology 91:1577–1586

An integrated treatment algorithm in ARDS is presented. Eighty-four patients with ARDS were enrolled in a 30-month period. If possible, the patients underwent computed tomography of the head, thorax, and abdomen before admission to the ICU. All patients were treated with conventional therapy:

1. Mechanical ventilation with a PEEP of 12–15 cmH_2O; peak airway pressure less than 35 cmH_2O; tidal volume 5–7 ml/kg. Management goals were: PaO_2 greater than 50 mmHg, arterial saturation over 90 %, and permissive hypercapnia up to $PaCO_2$ of 70 mmHg
2. Prone positioning every 4–12 h. Laparotomy, sternotomy, and tracheotomy were not considered absolute contraindications to the prone position.
3. Administration of nitric oxide from 5 to 20 ppm. A 20 % increase in PaO_2 or a mean pulmonary artery pressure decrease greater than 20 % were aimed at.

The efficacy of the conventional therapy was evaluated. A proportional hazard (Cox) regression showed that mortality is predicted by total days on mechanical ventilation ($P < 0.001$), days on mechanical ventilation prior to admission ($P < 0.004$), and APACHE II score at admission ($P < 0.05$). The application of this multi-step protocol in all patients improved survival and reduced the incidence of ECMO utilization.

Liebold A, Reng CM, et al (2000) Pumpless extracorporeal lung assist – experience with the first 20 cases. Eur J Cardiothorac Surg 17:608–613

Twenty adult patients (41 ± 16 years) were referred for ARDS. In association with a conventional multiple-step therapy, an artificial arteriovenous shunt (heparin-coated cannulae) with a low-resistance membrane oxygenator (Quadrox heparin-coated hollow fiber) was employed (pECLA). A stable hemodynamic status (CO over 6 l/min and MAP under 70 mmHg) was established by generous administration of catecholamines. The priming volume of the circuit was 270 ml. A continuous heparin infusion was used to reach a clotting time in the 130–150 s range (less than during classic ECMO procedure). A safe respirator setting was used. The mean duration of pECLA therapy was 12 ± 8 days with a mean extracorporeal flow of 2.6 ± 0.6 l/min. During 24 h of pECLA, mean PaO_2 rose from 45.9 ± 7 to 84.1 ± 21 mmHg ($P < 0.05$), while $PaCO_2$ decreased from 58.9 ± 17 to 32.7 ± 5 mmHg ($P < 0.05$). Fifteen patients (75 %) were weaned off bypass. The overall survival was 60 %. The pECLA appears to be contraindicated in patients with cardiac dysfunction (four patients died from septic shock and one patient from ventricular fibrillation). The technique seems, however, effective in patients with a good hemodynamic status: it is claimed to decrease the incidence of technical complications and the trauma related to hemolysis and coagulation disorders, thanks to mild blood anticoagulation.

Zwischenberger JB, Conrad SA, et al (1999) Percutaneous extracorporeal arterovenous CO_2 removal for severe respiratory failure. Ann Thorac Surg 68:181–187

The authors applied to five patients with severe respiratory failure an arteriovenous (femoral–femoral) bypass by a modified Seldinger technique with a low-resistance oxygenator (Affinity, Avecor Cardiovascular, Plymouth, Minn., USA). The goal of the study was to remove CO_2 in patients with permissive hypercapnia (pH > 7.2) and decrease the peak inspiratory pressure below

35 cmH_2O. The five patients were strongly anticoagulated (activated clotting time 280 ± 20) on account of the low AV shunt blood flow (600–1098 ml/min). The production of CO_2 and the percentage of CO_2 removed from the natural lung and the oxygenator were computed. The shunt was applied for 72 h and was able to remove approximately 70% of the total body CO_2 production (average $PaCO_2$ from 93.6 ± 9.0 to 69.0 ± 10.0); the mean PIP decreased from 33.0 ± 7.4 to 29.0 ± 7.5 cmH_2O and the tidal volume from 416 to 284 l/min. In two patients the PaO_2/FiO_2 ratio increased dramatically in 72 h; on the other hand, in three patients the PaO_2/FiO_2 ratio did not change. All patients were weaned from bypass and three survived.

Reng M, Philipp A, Pfeifer M, Gruene S, Schoelmerich J (2000) Pumpless extracorporeal lung assist and adult respiratory distress syndrome. Lancet 356:219–220

Pumpless extracorporeal lung assist (ECLA) was offered to ten ARDS patients who fulfilled the slow or fast entry criteria of the NIH-ECMO study. The treatment established an arterovenous shunt ranging from 16% to 37% of the cardiac output; the need for catecholamine never exceeded 5%. Relevant oxygenation and carbon dioxide elimination was achieved. No ECLA-induced bleeding was described. Mean duration of the oxygenators was 10.8 days

Discussion

These different studies exemplify the present application of extracorporeal lung support. The study by Ullrich et al. shows the application of a multiple step protocol before ECMO, with a survival rate higher than 80% without ECMO; on the other hand, the survival rate of "non-responders" reached only 62% in spite of ECMO. In the series of 100 ECMO patients presented by Kolla et al. the survival rate was 54%; however, 41 of the 141 (29%) patients referred for ECMO survived without extracorporeal support and the overall survival in the study was 62%. These two studies providing a large number of patients emphasise: (1) the capacity of the conventional therapy to allow healing even in extremely ill patients and (2) the actual number of ECMO complications, mainly related to the unavoidable systemic anticoagulation regime. The review by Struber and Haverich confirms the value of the improvement of the medical treatment for ARDS both before and during ECMO procedure in order to reduce the duration and the complications of the extracorporeal procedure. Also included in this line are the studies from Liebold et al. and Zwischenberger et al.: the use of extracorporeal CO_2 removal with a low regime of anticoagulation (Liebold) and low flow (Zwischenberger) without pump are able to decrease $PaCO_2$ and allow recovery of hemodynamically stable ARDS patients. Reng's article further supports the potential of extracorporeal oxygenation: in addition to the efficacy of the device, the long-lasting performance of the oxygenators without a blood pump is underscored. Technological improvements of the extracorporeal circuit (low blood-resistance oxygenator, heparin-coated cannulae) together with better understanding and assessment of conventional medical therapy are the up-to-date tools to treat the most severely affected ARDS patients.