Extracorporeal Membrane Oxygenation (ECMO) in Trauma

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Key Points

- Do not hesitate to use ECMO when respiratory and circulatory parameters are irreversibly worsened.
- Use a circuit as short as possible; the relationship between resistance and circuit length is directly proportional: flow resistance within the circuit increases when the circuit is longer. Moreover, longer circuit lengths have a greater contact surface for flowing blood inside it, a greater need for priming solution, and greater heat loss. The circuit should only be long enough to go safely from the patient to the pump and facilitate patient transport.
- It is better to use fewer connectors as possible. Each connector within the circuit causes the creation of a turbulent flow area. In these areas, clots may form more easily.
- Check for the absence of kinks, twists, and the right connections of the fluid tubing in the entire circuit.
- Use only what is essential for the good performance of the circuit as it makes it in such a way that it is possible to deal with unforeseeable situations.
- Dual lumen cannula insertion in the jugular vein should be done under transesophageal echocardiographic control for the risk of myocardial perforation.
- In VA (veno-arterial)-ECMO, avoid limb ischemia by using end-to-side chimney graft or by positioning a distal perfusion cannula.

53.1 Introduction

Polytrauma patients in most cases succumb to severe head and/or thoracoabdominal injuries. The trimodal mortality model in trauma, introduced in the 1980s [1, 2], refers to immediate deaths, early deaths, and late deaths. According to this model, there is a first mortality peak where death is immediate or occurs within minutes of the trauma or 1 h of arrival to the hospital; the reported mortality rate was up to 64%. The second mortality peak shows death occurring within 24 h of hospital arrival, determining up to 30% mortality [2]; once again, mortality is a consequence of massive lesions that may be effectively treated. Finally, the late death, which in Trunkey's description [2] accounts for about 20% mortality, is defined as deaths occurring days or weeks after the trauma. The subsequent development of regionalized trauma networks with rapid transportation of patients from the scene to specialized trauma centers [3], along with improved imaging modalities and surgical techniques, has determined a significative mortality reduction. Therefore, in traumatic lung injuries that do not respond to conventional mechanical ventilation, other treatments may help: chemical paralysis [4], prone positioning, inhaled prostacyclins, and pressure-controlled inverse ratio ventilation [5]. When all these treatment provisions are not adequate, and lung compliance becomes worse, the increased inspiratory pressures may cause barotrauma and further impaired lung function. Furthermore, ECMO should be used in case of traumatic bronchopleural fistula that is associated with very high mortality up to 67% with important morbidity [6, 7] and as a bridge to surgery in trauma

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patients with low tracheal lacerations or transections that cause respiratory failure by inadequate alveolar ventilation due to V/Q (ventilation/perfusion) mismatch from severe air leak [8–11]. If trauma affects only one lung, ECMO allows a selective ventilation of the healthy lung, while the injured one, collapsing, has time to heal [6, 8].

Nevertheless, trauma patients may present acute heart failure, e.g., due to a serious bleeding, to stunned heart following direct trauma (severe contusion and hematoma), or to depression determined by acidosis and hypothermia.

In these cases ECMO has been proven to be an adequate therapeutic tool that may grant patient's tissue perfusion supporting cardiac and respiratory functions. Therefore, the clinical use of ECMO is becoming increasingly frequent showing a dramatic improvement in survival rate [8].

53.2 ECMO System

A standard ECMO circuit consists essentially of the following components (Figs. 53.1 and 53.2):

Fig. 53.1 ECMO system (with permission from Getinge, Germany)

(a) Blood pump. Semiocclusive roller pumps have been substituted by centrifugal pump where a spinning rotor generates flow and pressure. The pump must supply a flow rate of 75–150 mL/kg/min (patients <10 kg; <18 months) and 2400 mL/m^2/min for others. One widely used pump is the Rotaflow centrifugal pump (Maquet Cardiopulmonary AG, Hirrlingen, Germany) that is employed in combination with the Maquet® Rotaflow console [12]. This device has high durability, lower hemolysis, less blood pressure, and a reduced chance of forming a microemulsion. Several other ECMO blood pump systems are now available and placed on the market: Medtronic Affinity Centrifugal Blood Pump (Medtronic, Minneapolis, MN), Medos Deltastream pump system (Medos Medizintechnik AG, Stolberg, Germany), Sorin (Mirandola, Modena, Italy), and Thoratec (Pleasanton, California, USA).

(b) Oxygenators. These are devices that provide O_2 and eliminate CO_2 from the venous blood. One of the most widely used is Quadrox Maquet®, polymethylpentene (PMP) with Bioline Coating that has an approval for 14 days continuous use, and consequently the need for oxygenator replacement is significantly reduced [13]. It has the following technical characteristics:

- Blood flow ratio: 0.5–7 L/min.
- Priming volume: 335 mL.
- Effective gas exchange surface: 1.8 m^2.
- Effective heat exchange surface: 0.4 m^2.

Another oxygenator is Eurosets (Medolla, Italy) validated for 14 days of use (Europe only), providing both cardiac and respiratory support. The gas exchanger is coated with lipid-based phosphorylcholine coating, and it contains an integral heat exchanger.

(c) Air/oxygen blender and gas lines. The blender is utilized to mix air and oxygen into a gas source ranging from 21 to 100% oxygen. The blender is connected to the oxygenator via a simple tubing (Fig. 53.2).

(d) Heat exchanger. This device is positioned distal to the oxygenator to replace ambient heat loss and maintain patient temperature.

(e) Circuit tubing (cannulas and related lines) between the vascular accesses.

The ECMO circuit tubing consists of polyvinyl chloride (PVC) conduits treated with a biocompatible coating. Because blood is exposed to the non-biologic surfaces of the circuit, complex reactions may involve either the coagulation pathway or the inflammatory response pathway with activation of the coagulant complement and cascade. Anyway, the biocompatible coating does not eliminate these hematological reactions completely [14].

Cannulas used in extracorporeal circulation are tubes of polymeric material, designed to circulate the blood with

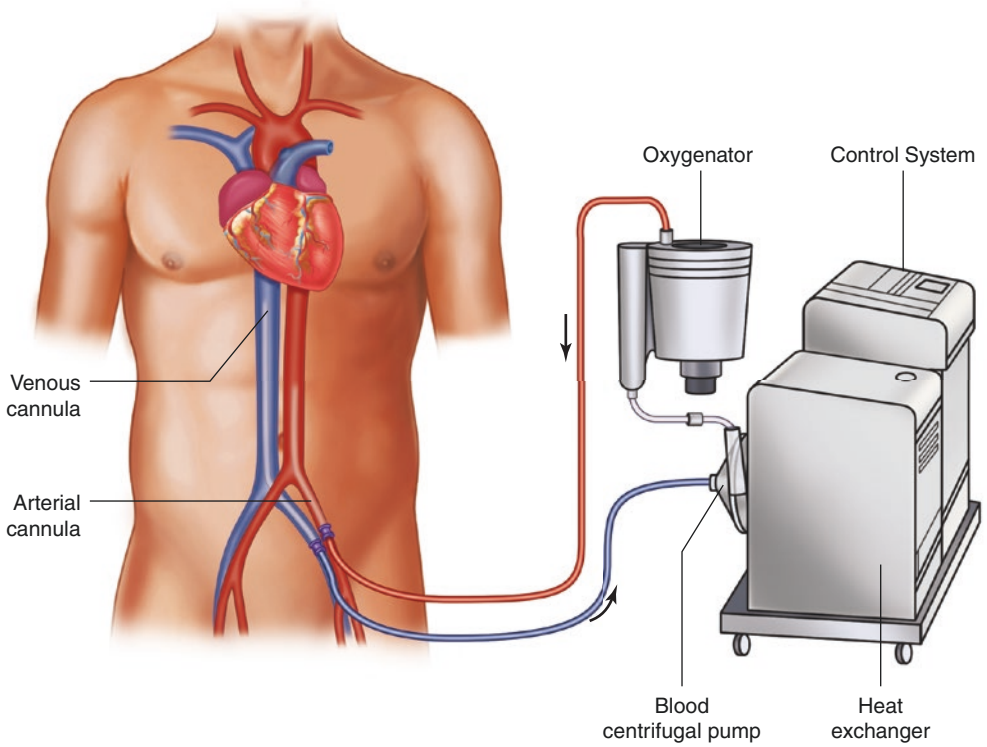

Fig. 53.2 Schematic standard ECMO circuit. (1) Venous cannula, (2) Blood centrifugal pump, (3) Oxygenator, (4) Arterial cannula, (5) Control system, (6) Heat exchanger

the lowest degree of turbulence [15]. Cannulas must also be "robust" enough to avoid bending or collapse, but, at the same time, they must be flexible and easily handled. Their gauge and length are the main determinants of the ECMO flow. The size of the cannulas must be sufficient to allow the optimum theoretical flow for each patient. The cannulas are tailored to peripheral use with a fine and durable wall that is wire reinforced in order to avoid bending and kinking.

The venous cannula presents an end hole and side holes to maximize drainage; furthermore side holes allow flow if the end is occluded.

There are *single lumen* (Fig. 53.3) and *dual lumen* (Fig. 53.4) cannulas. The first ones are utilized to provide venous (V) and arterial (A) access in patients who undergo VA-ECMO or in case of multiple site venous access in patients getting a VV-ECMO. For instance, the common site in the VV-ECMO is the femoral/jugular vein. A large cannula (23–25F) should be placed for drainage and somewhat smaller cannula (19–21F) for venous reinfusion.

There are several types of cannula with respect to design and size, ranging from 6F (2 mm diameter) to 51F (17 mm), and most of them are manufactured with wire-reinforced bodies to prevent occlusion [16].

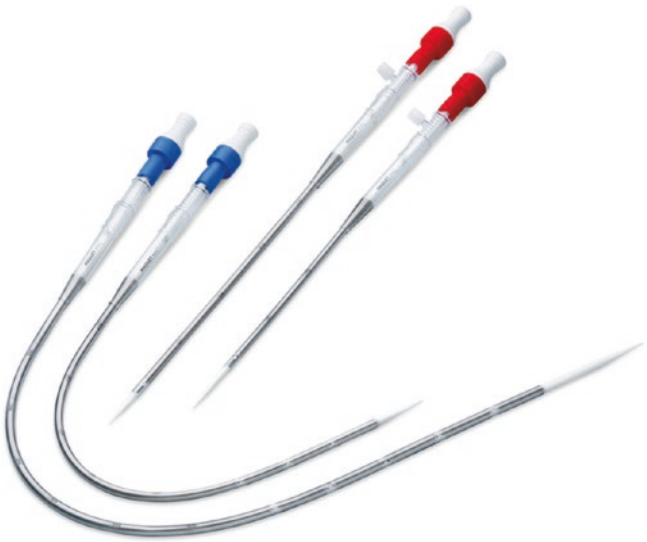

Fig. 53.3 Single lumen cannula (with permission from Getinge, Germany)

The dual lumen cannula is available for VV-ECMO using a single-vessel approach in the internal jugular vein: the blood is drained from one lumen and then is returned to the patient via the smaller one; for the

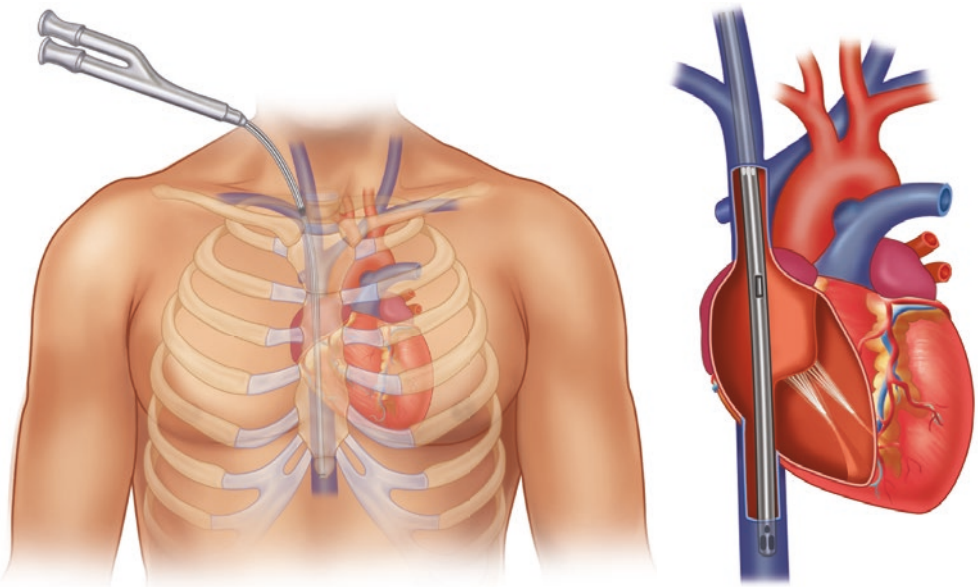

Fig. 53.4 Dual lumen cannula. Dual lumen cannula (with permission from Getinge, Germany)

Avalon dual lumen cannula, sizes range from 13 to 31F; other small cannulas are the OriGen (Austin, TX) dual lumen cannula that is available in 12, 15, and 18F sizes; it is manufactured from non-wire-reinforced polyurethane and may be subject to structural deformation after insertion; the Covidien ECMO (Mansfield, MA) cannula is also manufactured from non-wire-reinforced polyurethane. It is only available in 14F overall diameter [14]. For smaller sizes, it is recommended to position this type of cannula under transesophageal echocardiographic control for the risk of cardiac perforation [8, 17].

(f) Interhospital transport circuit. The Maquet Cardiohelp System is the smallest portable heart-lung support system designed to treat and to transport patients needing extended respiratory and/or circulatory support (Fig. 53.5). The Maquet Cardiohelp HLS modules integrate three major Extracorporeal Life Support (ECLS) circuit components (oxygenator, pump, and heat exchanger) into a single product. The system is coated with the Maquet Bioline thromboresistant surface [18].

(g) ECMO circuit. The ECMO circuit includes an outflow cannula connected to an outflow line linked in turn to a centrifugal pump. The pump injects the blood through an oxygenator and the heat exchanger in the inflow line. The arterial blood is reinjected to the patient by an inflow cannula.

In the acronym VA-ECMO, the drainage site is positioned prior the injection site, venoarterial ECMO; VV-ECMO means venovenous ECMO that can be femoro-right internal jugular veins (drainage from femoral vein and inflow in the jugular vein).

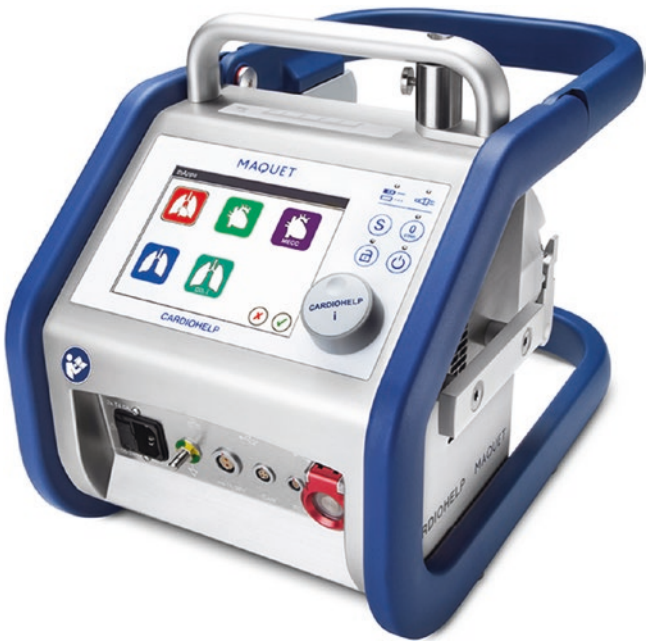

Fig. 53.5 The Getinge Cardiohelp System is a small and lightweight heart-lung support system (with permission from Getinge, Germany)

53.2.1 Venovenous ECMO (VV-ECMO)

– Double-site VV-ECMO is the most efficient technique for respiratory support, especially in case of high level of O_2 requirement [19]. The right internal jugular and the right or the left femoral veins are cannulated percutaneously. The right or "ideal" position of the outflow and the inflow cannulas are the junction between the right atrium and the inferior vena cava and the superior vena cava, respectively. The outflow cannula insertion length corresponds roughly to the length between the skin insertion point and the

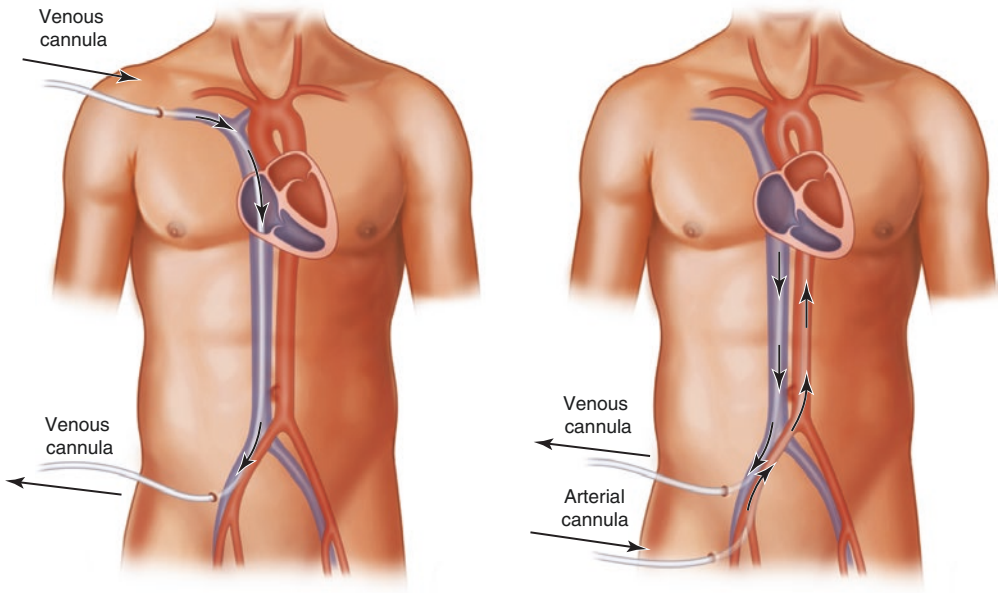

Fig. 53.6 On the left, schematic drawing showing venovenous ECMO: the venous blood is drained from the right femoral vein, and inflow is in the right jugular vein. On the right, schematic drawing showing venoarterial ECMO: the blood is drained from the right femoral vein, and inflow is in the right femoral artery

xiphoid process. The cannula is positioned under echocardiographic control.

- It is very important to utilize large cannulas (e.g., 25 Fr femoral cannula and 24 Fr right internal jugular cannula); in this way the VV-ECMO flow may reach 8 L/min.
- Single-site VV-ECMO. It is obtained by a single-site dual lumen cannula, the Avalon elite™ (Avalon elite™, Maquet cardiopulmonary GmbH, Rastatt, Germany). The cannula is routinely positioned in the right internal jugular vein: the outflow lumen drains from both the superior vena cava and the inferior vena cava; the inflow port is placed directly in the right atrium, in front of the tricuspid valve (Fig. 53.6).

53.2.2 Venoarterial ECMO (VA-ECMO)

VA-ECMO is indicated in trauma patients that present circulatory collapse and cardiogenic shock: in most of the cases it is positioned with a femoro-femoral access. Arterial and venous cannulas are positioned in the femoral vessels using the Seldinger technique with a completely percutaneous approach or after surgical cutdown. In the latter we cannulate the femoral vessels from the same side; surgical exposure allows to introduce under direct vision the cannula: a double purse-string suture around the insertion point will prevent air embolisms and hemorrhagic leaks and tie the cannula in place. Limb ischemia, the most frequent complication, is avoided by using end-to-side chimney graft or supplying blood by positioning a distal perfusion cannula (Fig. 53.7). If it is planned a percutaneous procedure (e.g., heart catheterization), it is better to utilize the femoral artery from one side and the femoral vein from the other side. The size of the venous cannula should be as large as possible (e.g., 25 Fr).

The size of the injection cannula depends on the caliber of the femoral artery and constitutes a balance between the risk of the inferior limb ischemia and the maximal flow available. It seems that a 21F inflow cannula is an optimal size in this configuration.

53.2.3 Anticoagulation

Chen and al [20]. describes minimal or none systemic heparinization reaching the target activated coagulation time (ACT) at 170 s. Ahmad [5] suggests, if not contraindicated in the patient, to maintain anticoagulation using heparin with ACT 160–180 s. Arlt and colleagues [21] (University Hospital Regensburg, Germany) reported initially heparin-free ECMO in severe trauma patients with resistant cardiopulmonary failure and coexisting bleeding; they found an improvement in therapy and outcome even in disastrous trauma patients. These findings were confirmed by Bonacchi et al. [22]

53.3 ECMO Support in Potential Organ Donors After Brain Death Determination

An increasing number of trauma patients, despite appropriate and immediate control of life-threatening injuries, may progress to brain death. In an attempt to counteract the

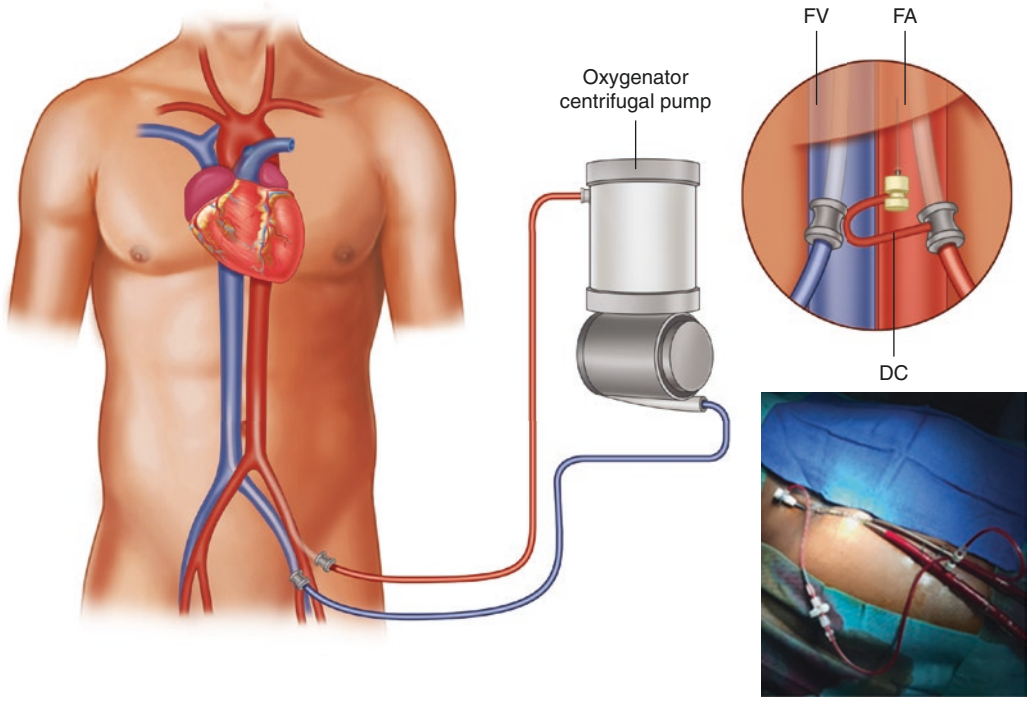

Fig. 53.7 Surgical approach to femoral vessels (*FV* femoral vein, *FA* femoral artery); in the enlarged circle, there is the distal perfusion cannula (DC), inserted distally the inflow arterial cannula. On the right, a surgical view: the two femoral, cannulas and and the DC that allows distal perfusion of the limb

worldwide organ shortage, in potential donors requiring aggressive vasoactive drugs, ECMO support should be considered in order to prevent damage and organ failure in case of transplantation. In this respect, there is an implementation of protocols that accept donation after cardiac death (DCD) and this measure has created a donor group that is frequently referred to as non-heart-beating donors (NHBDs). In brain dead potential donors organ perfusion must be optimized, endocrine homeostasis stabilized, and organs safeguarded; therefore, it is paramount to assure organ perfusion utilizing the least support of vasoactive drugs. Timing of ECMO support depends on several factors such as unstable hemodynamic (systolic blood pressure <90 mmHg) despite vasoactive drugs or a low oxygen saturation (SaO_2 < 90%) despite ventilation support with high levels of positive end-expiratory pressure and high fractions of inspired oxygen (FiO_2 > 80%). Therefore, A-V ECMO should be applied in early stages after brain death to perfuse abdominal organs before their retrieval; this practice has increased the organ supply for transplantation by approximately 20% in several countries. Furthermore, during the ECMO period the next of kin have the time to accept the death and to consider donation.

Another dilemma is: how long does the heart have to stop beating before you can declare a person dead? The time required to define the irreversibility of death varies widely among different countries. There is a no-touch period, defined as the time between the cessation of circulation and respiration and the determination of death, which ranges from 5 to 20 min. In Italy, the time interval to diagnose death is 20 min of cardiac arrest, demonstrated by continuous electrocardiographic recording. As matter of fact an interval time longer than that adopted in the United States and other European countries may negatively impact on organ viability, prolonging the warm ischemia time. ECMO support provides extra-circulatory support to patients with cardiorespiratory failure who would otherwise be expected to die. However, it should be remembered that in some studies, brain death has been reported as a complication of ECMO support. In this scenario, severe trauma patients with resistant cardiopulmonary failure and coexisting bleeding, the initial experience with heparin-free ECMO reported by Bonacchi [22] seems remarkable.

Finally it should be remembered that patients who are on ECMO support pose unique challenges to confirm the diagnosis of brain death. Brain death testing has been differently reported in the limited literature available with the majority of reports without information whether or not the patient remained on the ventilator with pressure support settings or he was taken off the ventilator. Due to the substantial continuous increase in ECMO utilization and the more frequent ethical and legal implications involved in brain death

declaration, it is imperative that consensus guidelines should be developed in order to guide clinicians to the brain death diagnosis in ECMO patients.

53.4 Results

ECMO circuit needs systemic heparinization, therefore its use in trauma is controversial because patients often present with intracranial lesions and acute coagulopathy and may require multiple surgical procedures. Moreover, trauma surgeons and intensivists are concerned about the high risk of possible lethal bleeding, and they hesitate to position ECMO in a trauma patient. Anyway, there are more and more studies showing that ECMO improves survival in trauma patients [22–25].

A recent study, from the Department of Surgery, University of Maryland School of Medicine (USA), showed the results with the use of ECMO from January 2006 to November 2015 [5]. During this period 46 patients were treated with ECMO, 39 (85%) received a VV-ECMO and of these, 17 (44%) patients survived to discharge. There were no survivors among VA-ECMO patients. Survivors had a lower BMI (median, 25.4 vs. 27.3 kg/m^2; $p = 0.046$), a higher arterial pH (7.4 vs. 7.2, $p = 0.02$), and a lower $PaCO_2$ (44 vs. 57, $p = 0.02$). Anyway, survivors and non-survivors were not significantly different with regard to sex (62% vs. 82% male, $p = 0.27$) and CCI (Charlson Comorbidity Index) (94% vs. 86% with CCI 0, $p = 1.00$); there was no difference in admission GCS (Glasgow Coma Scale), systolic blood pressure, serum creatinine, white blood cell count, hematocrit, platelet count, PaO_2 level, arterial pH base deficit, or vasoactive drip requirement between the two groups. Mortality is undoubtedly high, but it is important to underline that all the patients, before ECMO, had failed maximal medical therapy, and a 44% survival represents a significant improvement vs. a fatal situation. In this context, ECMO can play a role both as a hemodynamic (for myocardial contusion) and ventilatory (for pulmonary contractions, tracheobronchial fistulas) support. The presence of a pelvic hematoma caused by trauma is not a contraindication to femoral-femoral ECMO [26–29]. When immediate surgery is not appropriate in a patient with profound physiologic depletion, hypercarbia, hypoxia, and shock requiring vasoactive medication, a damage control approach by ECMO support should be strongly considered. In this way it may be possible to have an early control of hemorrhage and contamination, resuscitation in the intensive care unit, and delayed definitive surgery after normalization of patient's hemodynamics. However, since the current knowledge of ECMO support is based on observational experience and retrospective studies, prospective controlled trials are needed to gather more evidence on safety and efficacy of ECMO support in different clinical settings.

Case Scenario

A 65-year-old male, polytrauma patient, developed a severe ARDS (Acute respiratory distress syndrome); his FO_2/PO_2 ratio was 50 mmHg, and his peripheral O_2 saturation was 80% despite maximal mechanical ventilation. Blood pressure was 105/70 mmHg with minimal inotropic support and heart rate 118/min. He was connected on VV-ECMO: a return cannula was inserted into the right atrium via the right internal jugular vein (19F), and a drainage cannula was inserted into the right femoral vein and positioned in the inferior vena cava. Thirty minutes after ECMO started, the patient remained severely hypoxic despite a circuit flow of 5.5 L/min and a post-oxygenator saturation in O_2 of 100%. Increasing pump speed to 4.500 rpm and circuit flow to 6.5 L/min did not ameliorate respiratory data. Arterial O_2 saturation is 83, while O_2 saturation in drainage line is 79%.

1. What is the most probable reason for the persistent hypoxemia?
   A. An oxygenator defect.
   B. Recirculation of blood between the return and drainage cannulas.
   C. Bilateral massive pneumothorax.
2. What would you suggest to do to improve hypoxemia?
   A. Change oxygenator.
   B. Adjust the cannula position: the return cannula tip should be positioned in the right atrium toward the tricuspid valve.
   C. Arrange for a VA-ECMO.

Please see Chap. 58 for the correct answer.

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