Chapter 5
Monitoring the ECMO

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As we saw in the previous chapter, the ECMO device is complex and requires a precise, thorough, and constant management.

The aim of this chapter is to describe and explain the different aspects of managing ECMO patients at bedside after implantation. We will be discussing here only about centrifugal pumps. The monitoring of an ECMO patient starts first like the surveillance of any ICU patient starting with a head-to-toe assessment of the patient:

- Vital signs: heart rate, mean arterial blood pressure (MAP), temperature, saturation, central venous pressure (CVP)
- Physical assessment noting: hypoperfusion signs, sweating, moisture level
- Neurological status: consciousness, pupillary reaction
- Check of all the devices: IV lines, dressings, ventilator, infusion pumps

In addition to these regular rounds will be added the monitoring of the ECMO device itself and the surveillance of all the potential risks linked to the ECMO.

5.1 Monitoring the Circuit

5.1.1 The Circuit Check

It is a complete check up of the ECMO: plugs, fluid connectors, alarms, the integrity of the whole circuit:

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- *The position of the device*: The ECMO cart should be placed on brake position, with the controller facing the entrance of the patient's room. It allows any caregiver to have a visual on the parameters immediately as he enters the room.
- *Power supply*: Check that the ECMO is correctly plugged, if possible, to a secure plug (a red power outlet). Every ECMO device, whatever the brand, has a power and a battery light on the controller; make sure the battery light is off and the power light is on.

  On some device, there is an additional on/off switch next to the plug itself.

  Finally, make sure the power supply alarm is switched on which alerts you in case of an accidental unplugging or an electrical dysfunction.
- *Fluid connections*: Fluids (air and oxygen) are connected to a blender which ensures gas exchanges. This blender is then connected to the oxygenator of the ECMO via a simple tubing. Check the absence of kinks, tensions, and the right connection of the fluid tubing to the oxygenator and gas hoses.
- *The cannulas and tubing*:
  - For the ECMO to run properly, there must be no kinks on the full length of your cannulas. The sutures of the cannulas have to be in place. The presence of tie-bands in the appropriate places and the safety of all connectors should be checked. The entire circuit (tubing and oxygenator) must be inspected with a flashlight, looking for clots and/or fibrin , and more specifically the connectors, pigtails, or stopcocks that may be on the circuit. Every center has its own tubing configuration, from a simple loop getting in and out the patient through the pump and the oxygenator, to more complex circuits with bridges, multiple pigtails, stopcocks to allow monitoring pressures, use as IV access to infuse volume or medication. The more connections that are present on the circuit, the more stagnation of blood is created. It enhances the risk of clot formation. That is why complex circuits must be watched with much more caution.
  - The ECMO (VV or VA) allows blood oxygenation. Hence, there is a color difference between cannulas: the admission cannula is dark red, deoxygenated blood, and the reinfusion cannula (starting after the oxygenator) is light red, oxygenated blood. The nurse should check this color difference between the cannulas (Fig. 5.1).

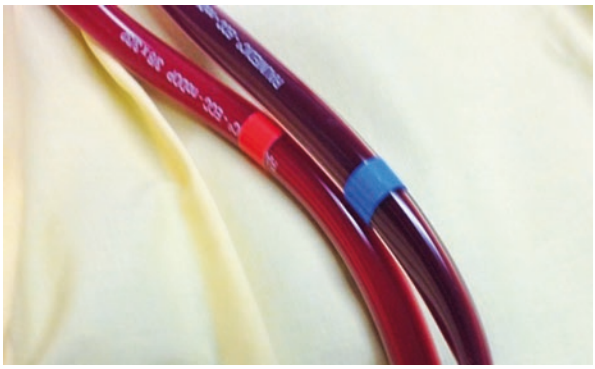

Fig. 5.1 Color differenciation of the tubings

- *The circulatory parameters of the pump*: Circulatory support is the essence of the ECMO, to ensure a correct support or replacement of the cardiac function for VA ECMO or to ensure an adequate gas exchange for VV ECMO.

  The pump being nonocclusive, the flow rate must always be above 2 L/min. Under that flow rate, there is a risk of backflow, leading to an inefficient ECMO run.

  The ECMO flow depends on a few parameters:

  – The preload: determined by volemia, venous tone, the position, and the size and length of the admission cannula.
  – The afterload: determined by vascular resistance, the position, size and length of the reinfusion cannula, and the length of the tubing between the pump and the oxygenator.
  – Cannulae sizes: 17–19 Fr for reinfusion cannuale, 21–23 Fr for admission cannulae, and 5 Fr for the reperfusion line for PVA ECMO.

The parameters are the rotations per minute (RPM) and the blood flow. The therapeutical goal set by the team is the blood flow. For the nurse, writing down these two parameters has no relevance. The correlation of the RPM and blood flow and its evolution through time will allow an effective management of the ECMO run. For example, at 2 pm, the RPM is set up at 4500 L/min for a blood flow at 4 L/min. At 5 pm, for a similar RPM, the blood flow went down to 2.5 L/min. It can be a sign of hypovolemia maybe due to blood loss or the patient may have moved and kinked partially part of the tubing.

- *The setting of the gas blender*: The blender ensures gas exchanges through the oxygenator—oxygen supply is adjusted via the FiO_2 and the CO_2 removal via the gas flow. It is essential to write down at each round the gas blender settings. In addition to patient's saturation, ventilator's settings, and blood gases results, it enables a timely decision-making.
- *The alarms*: They must be set regarding the therapeutic goal. The pump being nonocclusive, it is recommended to maintain the blood flow above 2 L/min to avoid any backflow.

  It is also crucial to know on which mode your ECMO is working.

  In a free mode, when an alarm is activated, the ECMO will keep working, but when the ECMO is on intervention mode, as soon as an alarm is set on, the ECMO stops working, and an immediate action must be set to resolve the problem. The choice of the mode depends on the human resources; if a nurse, ECMO specialist, or a perfusionist is constantly present at the patient's bedside, the intervention mode is possible, but if a nurse is taking care of more than one ECMO patients and cannot intervene immediately when the pump stops, the free mode will be safer.
- *The emergency kit:* It should be available at the bedside or in the unit, allowing an immediate response to any adverse events—clamps, emergency hand crank, emergency supplies (appropriate-sized connectors/shears/tubing/rapid access line, fluid, tie-gun and tie-straps/sterile gloves, preprimed pump, etc.)

5.1.2 The Pressure Monitoring

Monitoring pressures is not essential, but it is an additional tool to help the team detect a potential and/or immediate dysfunction of the ECMO. There are no exact target numbers to refer to. Pressures vary depending of the size of the cannulas, the ECMO flow, the patient volemia, etc.

Like explained sooner for circulatory parameters, it is not the number but the evolution of pressures through time that will help the team prevent dysfunctions. Again, it is crucial to write down at each ECMO rounds the pressure numbers in the patient's chart.

Three pressures are commonly measured (Fig. 5.2).

P_{vein} or Venous Pressure

It is the prepump pressure. It measures the pressure in the admission cannula. So, it is a negative pressure. It should not excced 100 mmHg.

A quick and significant rise of P_{vein} means the ECMO has difficulty to drain blood from the patient. It can be caused by a hypovolemia or by a kinked and/or occluded admission cannula.

P_{art} or Arterial Pressure

It is the post-oxygenator pressure. It measures the pressure in the reinfusion cannula. It is a positive pressure that should not exceed 200–250 mmHg.

A quick and significant rise in P_{art} may be caused by an increase of the patient's preload or a sign of a kinked and/or occluded reinfusion cannula.

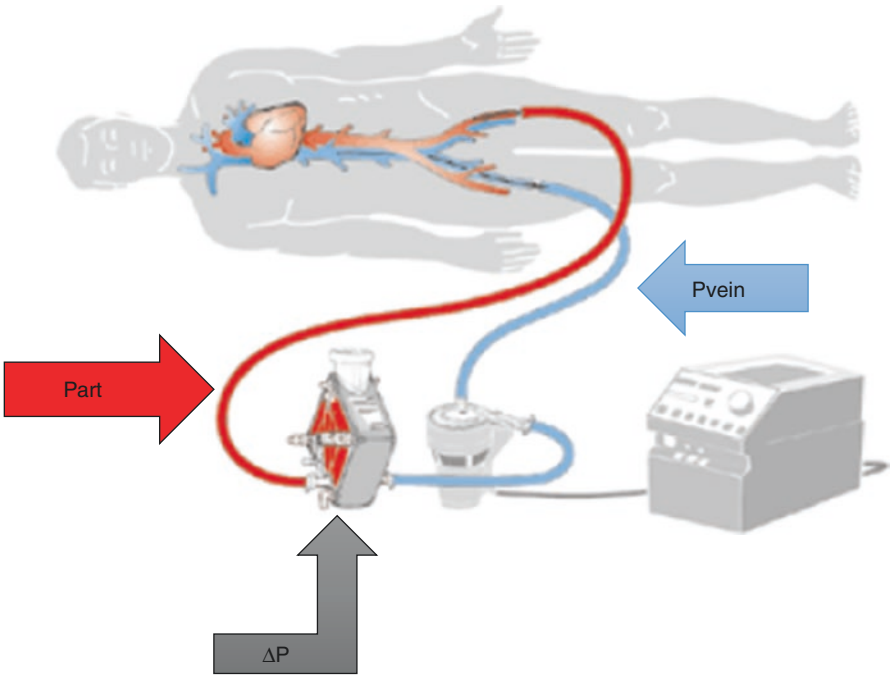

Fig. 5.2 Pressure monitoring (Courtesy of Maquet®)

Δp

It is the pressure difference through the oxygenator. It changes during the ECMO run. The speed of the rise depends mostly on the flow and on a good management of coagulation. It is an indicator of the level of saturation of the membrane of the oxygenator.

Any significant rise of Δp (+20 mmHg/h) must be reported immediately to the medical team. It can be a sign of clotting inside the oxygenator. This could evolve towards a pump failure.

These pressures can be monitored by:

- Adding pigtails to the circuit in the appropriate places and connecting them to a pressure monitoring system (similar to the ones used for arterial lines or CVP).
- New ECMO consoles have added the pressure monitoring function to their controllers, without the need to add any connectors to the ECMO circuit.

A pressure number alone is not a significant element; it is a tool that can help the team manage and assess the patient's ECMO run in addition to clinical exam, circuit control, and patient's blood panel. For example, a rise of 60 mmHg in the Δp in an hour could be a sign of clotting in the oxygenator, but this number alone cannot justify the replacement of the oxygenator. It has to be completed by blood gases to assess the ability of the oxygenator to perform gas exchanges efficiently.

5.2 Adapting the Specifics of ECLS to the Regular Monitoring of the Patient in a Critical Care Unit

5.2.1 Pain and Sedation

ECMO patients are now more commonly awake and even extubated sooner [1]. It is mostly the case for VA ECMO patients: they can be awakened just after ECMO implantation; some teams even implant the ECMO on nonsedated and extubated patients with local anesthetics. For VV ECMO patients, they are always deeply sedated the first few days due to the major lung damage.

The ECMO membrane lung is trapping medications, altering pharmacokinetics and pharmacodynamics of analgesics and sedatives such as propofol, midazolam, or opioids [2]. Higher doses of sedatives and analgesics must then be administered to obtain an appropriate sedation and comfort of the patient. Hence, protocols of management of pain and sedation should be reassessed for ECMO patients.

5.2.2 Infection

Like any other device inserted inside the patient, the cannulas can be a source of infection. ECMO cannulas, being of large diameters, enhanced the risk. The site of cannulation worsens this potential complication: drowning can soil jugular

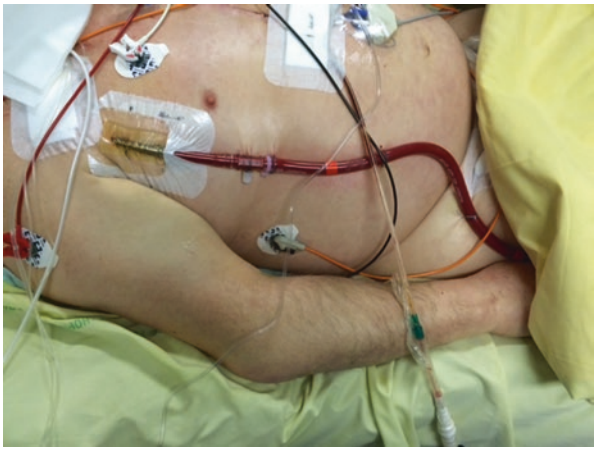

Fig. 5.3 Transparent chlorhexidinie gluconate impregnated dressing

cannulas, stool contaminates femoral cannulation, and central cannulation is directly inside the heart of the patient.

Early detection is of paramount importance; the nurse should check:

- Daily white blood count and cell blood culture
- At each round, the integrity of the cannula dressing
- A daily assessment of the insertion point of the cannulas, looking for redness, swelling, bleeding, or potential infection

In central lines, the use of chlorhexidine gluconate-impregnated sponge reduces the infection rate, diminishes the frequency of dressings up to 7 days, and allows a visual on the insertion point [3]. It can be done with the ECMO cannulas (Fig. 5.3).

5.2.3 Skin Care

Skin care is a constant challenge for ICU nurses. ICU patients have always been good candidates for developing pressure sores: they are lying in bed most of the day, often sedated; infection and heparin infusion can provoke skin abrasion or hematoma; and edemas are unavoidable, specially for patients with heart failure.

ECMO patients, in addition to these preexisting skin alterations, must face other potential skin damages: cannula's sutures are tight and through time lesions can appear. Edema plus the pressure of the cannula on the skin can lead to unavoidable pressure sores.

Protecting the skin from the cannulas can be done with foam dressings or hydrocolloids already used for regular patients. To fix the cannulas without damaging more skin, some attachment devices like the horizontal tube attachment are composed of hydrocolloid, allowing skin protection and an additional fixation (Figs. 5.4 and 5.5).

Fig. 5.4 Horizontal tubing attachement device (Courtesy of Hollister®)

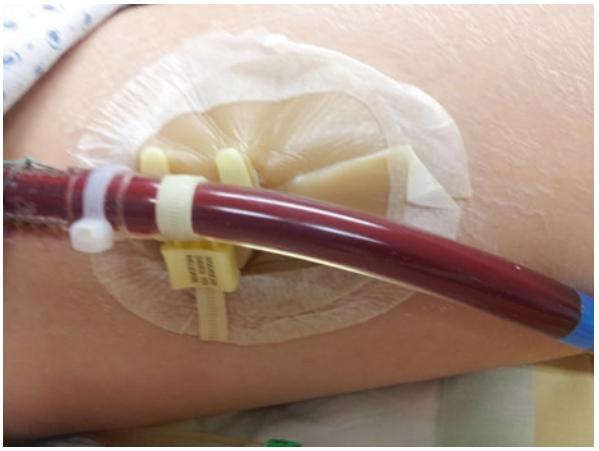

Fig. 5.5 Horizontal tubing attachement device on an ECMO patient

5.3 Preventing Complications

ECMO is a miniaturized version of the extracorporeal circuits used in the operating room for thoracic surgery. An ECMO run is therefore the source of minor to major complications, endangering the patients.

One of the key points of ECMO management is to prevent and make an early detection of these complications. All the ICU caregivers (doctors, nurses, perfusionists, physiotherapists, respiratory therapists, help nurses) must be trained to acknowledge the signs of an early bleed, an infection, and a dysfunction of the ECMO.

5.3.1 Bleeding

Bleeding is frequent and can be massive during any ECMO run. The blood of the patient is in contact with an inert and nonbiological material, so continuous systemic anticoagulation by nonfractionated heparin infusion is necessary to prevent fibrin and

clot formation in the ECMO circuit. During implantation, a bolus of 5000 UI of heparin is most commonly injected to the patient, enhancing the risk of bleeding. In the immediate postimplantation phase, the challenge is to be able to balance the control of postoperative bleeding as well as minimizing the formation of clots in the ECMO circuit. Bleeding can also be worsened after an open heart surgery or transplant.

5.3.1.1 Prevention

To prevent bleedings, a very strict control of the hemostasis is necessary: the heparin infusion rates have to be titrated to obtain an aPPT ratio between:

- 1.8 and 2 times normal level for VA ECMO patients depending on their cardiac condition; the antifactor Xa can also be a better indicator of the heparin management
- 1.5 and 1.8 times normal level for VV ECMO patients
- 2 and 2.2 times normal level for ECMO circuits with more than two cannulas like VAV, central cannulation

5.3.1.2 Clinical Signs and Treatment

Bleeding on ECMO can be local or generalized:

- *The Ear, Nose, and Throat (ENT) area*: Bleedings in this area are almost unavoidable. Mouth care is then difficult, and sometimes ineffective. With a nose bleed, the nurse can start by digitally pressuring the nostrils for a 5-min period. If the bleeding persists, insert a resorbable hemostatic wick in each nostril. If this technique fails too, the last resort is to insert a nasal compression probe (it is possible to use a urinary catheter). By inflating the balloon of the probe, a compression is made in the posterior fossa, stopping the bleeding.

  For the mouth, oral care stays crucial even if it seems ineffective. The mouth of the patient should still be gently suctioned to remove drooling, blood, and clots, and cleaned with smooth mouth sticks but only with water. Mouthwashes usually contain alcohol, which can maintain the bleeding and provoke a burning sensation to the patient. In the most severe bleedings, ENT specialist can perform a packing of the mouth: the entire oral cavity and throat will be then packed with hemostatic wicks. Oral care is then impossible, but to avoid pressure ulcer on the palate and tongue, the "packing" must be humidified with saline every 4–6 h and completely removed after 48 h.
- *The dressings:* Bleedings can occur on all the patient's dressing, insertion point of IV lines, suction drains, and ECMO insertion point. The use of hemostatic dressings can avoid redoing the dressings several times a day.
- *The neurological status of the patient:* Look for any signs of intracranial hemorrhage—bilateral pupillary response, level of consciousness, patient's reaction to the decrease of sedatives [4].
- *The aspect of the lung secretions*: Intra-alveolar hemorrhage can occur. Bleeds can be related to the disease itself, especially for patients on VV ECMO with

severe ARDS, but it can also be caused by a disseminated intravascular coagulation (DIC) for patients on VA ECMO. It is recommended for patients on VV ECMO to use a humidifier on the ventilation tubing. Warming and humidifying the bronchial tree could minimize clot formation.

- *The aspect of the urine:* Although rare, presence of blood in urine can occur. The urine color is then bright red. Be careful not to cofound it with the "dark reddish" color of the urine in case of hemolysis.
- *The digestive tract*: Presence of blood in stools can be seen. If there is a doubt, use hydrogen peroxide on a stool sample. If foam appears, it means there is blood. In the absence of external bleeds or in severe DIC cases, a gastric lavage should be performed to check the presence or absence of blood.
- *General treatment*: It is essential that the team understands and finds the right balance between pro- and anticoagulants to manage the patient properly. The daily blood count can assess the blood loss and the need to transfuse the patients with packed red blood cells or platelets. It is still a debate in the ECMO community to determine the cutoff for red blood cells transfusion; some teams (La Pitié Salpêtrière is part of them) recommend to transfuse only when the hemoglobin is under 7 g/dL; others argue that an ECMO patient should have a normal hemoglobin to allow an optimized oxygenation, so that the transfusion limit will be 12 g/dL.

  For long, ECMO teams have been reluctant to discontinue heparin during ECMO runs. Experiences from several teams and data show that in case of severe hemorrhage and if the patient is nonresponsive to transfusion and a decrease rate of the heparin infusion, the discontinuation of the heparin is possible [5] for hours and even days, with a strict control of the aPPT and a thorough check of the oxygenator and cannulas looking for clots and thrombin. In a worst case scenario, using recombinant factor VIIa has been done safely by several teams with a major decrease of bleedings, but must be a last resort therapy with an extreme caution and surveillance of the ECMO circuit [6–8]

5.3.2 Thromboembolic Risk

Good and effective anticoagulation treatment not only avoids bleeding but also prevents formation of clots and thrombin. They are the results of cells lysed by the turbulence of the ECMO pump and the stagnation of blood. They are easily visible with a flashlight within the tubing and connectors: dark clots and white fibrin strands can be easily observed.

Meticulous surveillance is of paramount importance: detection, documentation, and the evolution of clots and fibrin can prevent major adverse events like brain damage or ECMO failure due to pump or oxygenator thrombosis (Figs. 5.6, 5.7, and 5.8).

At each round, the nurse must inspect the entire ECMO circuit with a flashlight: the cannulas, the connectors, the pigtails, stopcocks, the pump, and the oxygenator. The challenge for the nurse is to differentiate "normal" clots and "bad clots." "Normal clots" are small and have no risk to harm the circuit or the patient. They are frequently seen at the top of the oxygenators, where the blood stagnation is not preventable. The "bad" clots are the ones becoming an obstacle to the blood flow,

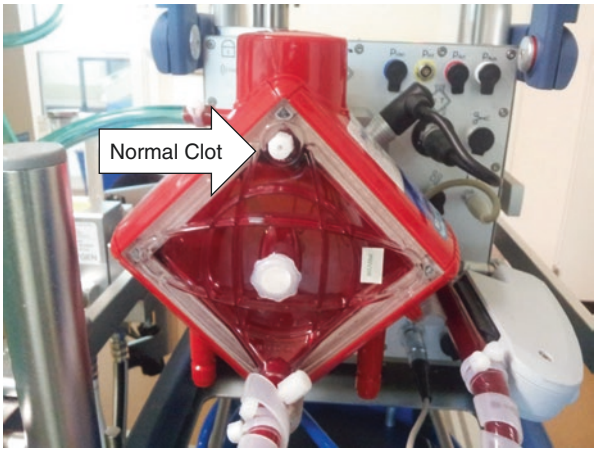

Fig. 5.6 Normal clot on the arterial side of the ECMO oxygenator

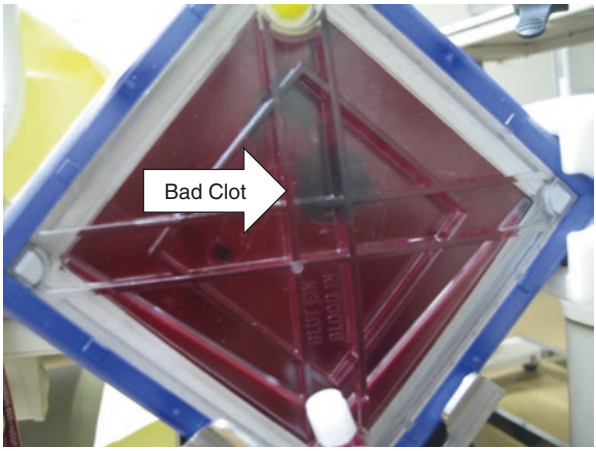

Fig. 5.7 Abnormal clot on the ECMO oxygenator

the gas outlet, and causing pressure changes through the membrane. Also, the clots formed on the "arterial" side of the oxygenator, from which the blood goes back directly to the patient. If a clot detaches and goes back to the patient's bloodstream, it can cause cerebrovascular accident.

If clots and/or fibrin are jeopardizing the efficiency of the ECMO therapy or expose patients to brain damages, the ECMO circuit should be changed. Depending on the team's strategy, we can either change the component or change the whole circuit. But, the assessment of changing an oxygenator must not depend solely on the presence of clots. Clots are one parameter; the efficiency of the membrane to complete the gas exchange properly stays the most important parameter.

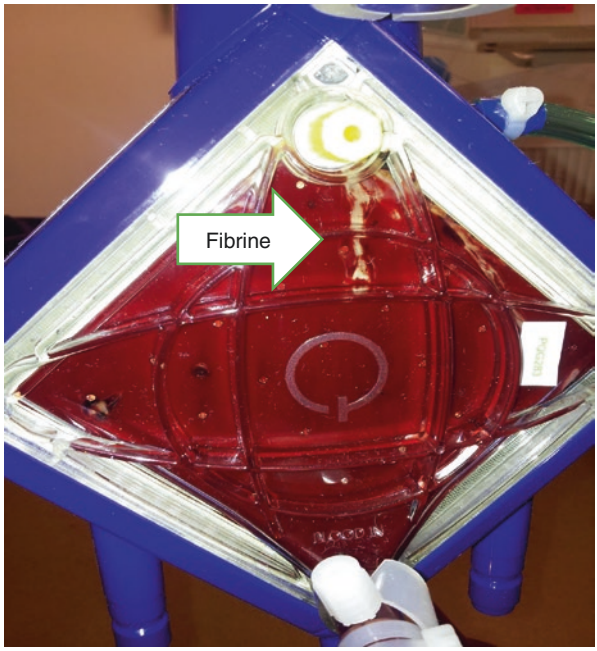

Fig. 5.8 Fibrine strand on the ECMO oxygenator

5.3.3 Hemolysis

The ECMO flow is generating spins and trauma to blood cells causing them to break and causebleeding. Hemolysis may occur due to

- Membrane failure (causing fibrin and clot formation)
- Pump with highly turbulent flow
- Clotting in the cannulas
- High-energy blood suction: hypovolemia, flow competition between the pulmonary artery and the left atrium admission cannula when the native heart function recovers

Prior to clinical signs, on the patient's daily blood panel, a rise of the free plasma hemoglobin above 50 mg/L, associated with a drop of platelets and red cell counts, can be seen. Clinically, the hemolysis shows with a characteristic bloodyish color of the urine or the effluent bag if the patient has no urine output (Figs. 5.9 and 5.10).

In uncontrolled cases, other external or internal bleedings can occur; ultimately, with no adequate treatment, the patient will develop DIC.

There are two sides to treat hemolysis:

- The symptomatic treatment: replacing the blood loss with packed red blood cells, platelets, and minor the bleeding with frozen plasmas
- The curative treatment: changing the ECMO circuit

Fig. 5.9 Typical aspect of the urine in case of hemolysis

Fig. 5.10 Typical aspect of the CRRT urine bag in case of hemolysis

5.3.4 Decannulation

It is a rare but feared complication. Inadvertent decannulation can be avoided by respecting simple but very strict guidelines before mobilizing a patient in and/or out of bed:

- The caregiver (nurse, ECMO specialist, perfusionist) must have a complete visual of the circuit (cannula, tubing, pump, oxygenator, controller).
- Check all fixations: tie-bands placed at all connectors, presence of sutures in appropriate places such as the insertion point and more importantly on the first connector (between the cannula and the ECMO circuit (Fig. 5.11).
- Additional fixations can be placed on the leg or torso using basic dressings, but it can generate pressure sores. Some horizontal drain fixation devices exist. They allow a good fixation and are made of hydrocolloids, which protect the skin of the patient (Fig. 5.12).

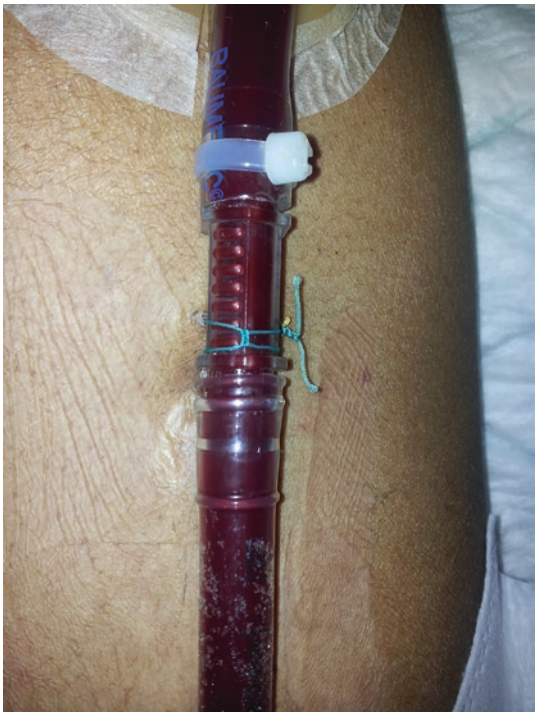

Fig. 5.11 Secured suture on the first connector between the cannula and the ECMO tubing

Fig. 5.12 Horizontal tubing attachement device (Courtesy of Hollister®)

5.4 Specifics of VA ECMO Patients

5.4.1 Hemodynamic Monitoring

The ECMO is a nonpulsatile device and generates a laminar flow. Right after implantation, most VA ECMO patients have a poor or no heart pulsatility.

Hence, the arterial blood pressure is delivered mostly by the ECMO. The patient's arterial line can look dampened or even flat with identical systolic, mean, and diastolic arterial pressure numbers, sometimes only with the mean arterial pressure. Inexperienced staff can think that the arterial line is deficient (Fig. 5.13).

When monitoring these patients, the aim is to maintain the mean arterial pressure above 65 mmHg.

The recovery of a pulsatile blood pressure is one of the signs of left ventricular function improvement.

As we will see later in 4.4, a balloon pump can be inserted to prevent pulmonary edema. In that case, the arterial line will regain a pulsatility caused by the balloon. To assess if the pulsatility is due to the balloon pump or the heart of the patient, pause the balloon for a few seconds and watch the arterial line: if it flats, then the native heart has not yet recovered.

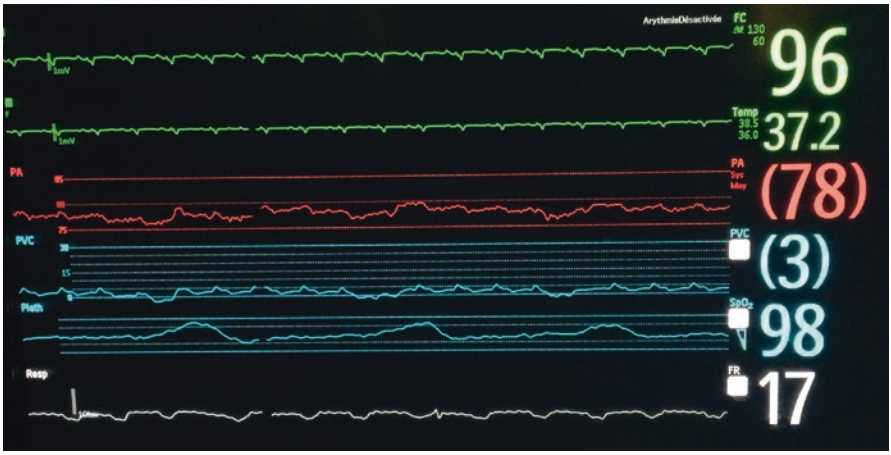

Fig. 5.13 Flat arterial line due to the laminar flow of the ECMO pump and the absence of heart contraction

5.4.2 *Limb Ischemia*

The femoral arteria is partially or totally occluded by the reinfusion cannula of the ECMO. Blood flow to the leg is then low or inexistent. To prevent limb ischemia, it is recommended to insert a reperfusion line in the superficial femoral arteria and connect it to the reinjection cannula to allow leg perfusion [9–11] (Fig. 5.14).

The nurse will monitor the leg by

- Comparing the temperature of both legs by touching or using oxymetrie or NIRS
- Checking the aspect of the leg: its stiffness, color: first white, then blisters, and, in the most extreme cases, foot necrosis (Figs. 5.15, 5.16, and 5.17)

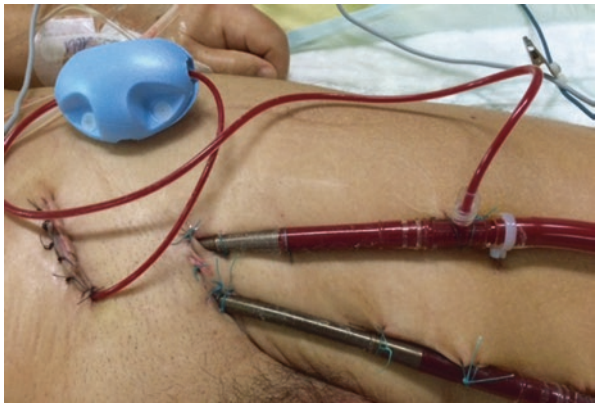

Fig. 5.14 Reperfusion line on a femoral peripheral VA ECMO

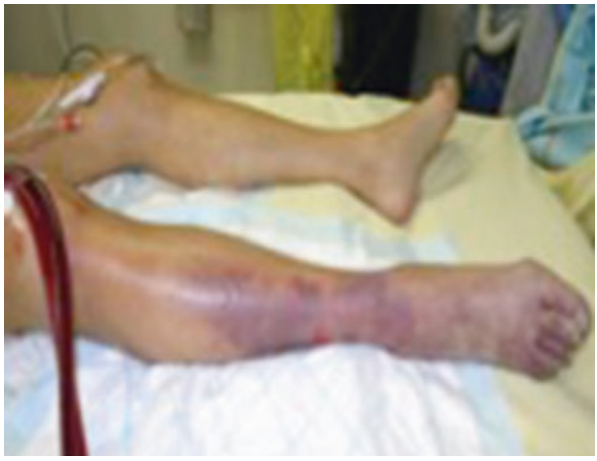

Fig. 5.15 Limb malperfusion on a patient with femoral peripheral VA ECMO

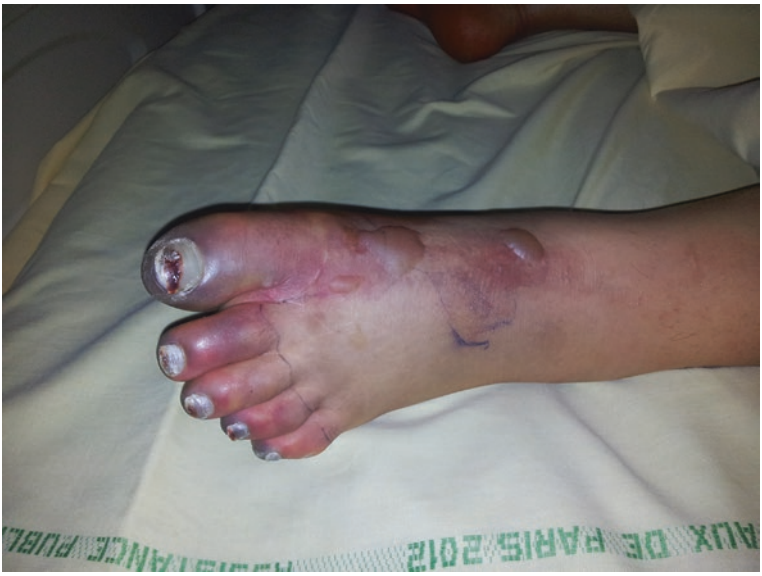

Fig. 5.16 Feet malperfusion on a patient with femoral peripheral VA ECMO

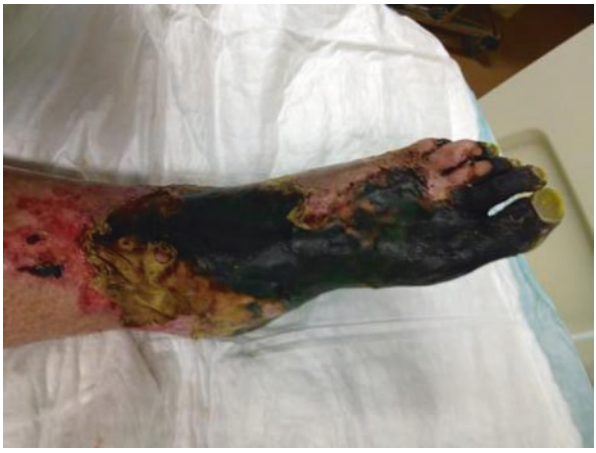

Fig. 5.17 Foot ischemia on a patient with femoral peripheral VA ECMO

The reperfusion line must always be visible through a translucide dressing, so that the nurse can check the absence of kinks, clots, and/or fibrin. On this picture you can see clots and fibrin on an occluded reperfusion line (Fig. 5.18).

The same ischemia can occur with axillary cannulation. A reperfusion line can be inserted to allow perfusion in the arm.

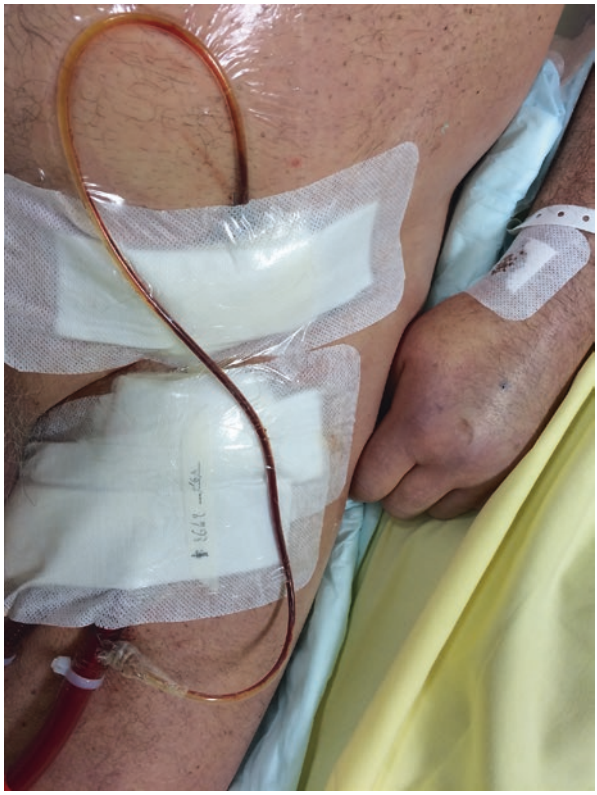

Fig. 5.18 Clotted reperfusion line

5.4.3 Differential Hypoxia

It only concerns patients on peripheral VA ECMO. It is also called the Harlequin syndrome, two circulations syndrome, or north/south syndrome.

In extreme cardiac dysfunction, if the heart is not beating and the aortic valve is not opening, the ECMO is providing 100% of the patient blood flow and oxygenation. The ECMO blood flow infused into the femoral artery is in a direction that is retrograde to the native blood flow. When the heart recovers a pulsatility and the aortic valve begins to open, fully saturated blood from the ECMO mixes with the blood ejected from the native ventricle in the aorta and create a mixing cloud. The location of this mixing cloud depends on the amount of ECMO support provided and the degree of left ventricular ejection. The mixing cloud moves proximally in the aorta when there is poor left ventricular ejection function and/or when the ECMO flow is increased. On the contrary, the mixing cloud moves distally in the aorta when the ventricle recovers and/or the ECMO flow is decreased. If the pulmonary function is impaired, the typical VA ECMO flow rate (80% of full cardiac output) can result in desaturated blood from the left ventricle perfusing the aortic arch, the brain, and coronary arteries, and fully saturated infusion blood perfusing the lower body. The patient's head appears blue, whereas the lower extremities appear pink.

To detect and/or diagnose differential hypoxia, the pulse oximeter must be placed on a finger of the right hand, and blood gases should be measured in the right radial artery, which reflects the patient's cardiac output.

To correct and treat this hypoxia, most teams add a jugular cannula to deliver oxygen to the brain.

5.4.4 Fluid Management

Finding the right balance between hypovolemia and fluid overload is more complex for patients undergoing VA ECMO, especially after cardiac surgery.

Massive blood losses are frequent after heart surgery, and the ECMO itself can worsen this loss.

At the bedside, the nurse can suspect hypovolemia with a chattering of the lines associated with sudden variations of the ECMO flow resulting in hypotension. The nurse must then administer enough volume to maintain an efficient ECMO flow (MAP >65 mmHg). Hypovolemia induces hypotension and an unstable and low ECMO flow. The variation of flow increases also fibrin and clot formation.

But, giving large volumes in association with muscle relaxants and venodilators can contribute to extraordinary amounts of unavoidable peripheral edema. Diuretics can treat this fluid overload. For patients not responsive (urine output <0.5 mL/kg/h, positive fluid balance >500 mL in the past 24 h), renal replacement therapy should be started.

Also, inefficient fluid management often results in pulmonary edema. The ECMO reinjects blood cross-current from the native blood flow. In VA ECMO patients with poor or no cardiac function, this generates an increased afterload, causing pulmonary edema.

Implanting a CPIAB at ECMO initiation could prevent it by unloading partially the left ventricle [11, 12].

To treat pulmonary edema, the aim is to unload the left ventricle. If conventional treatments like the use of diuretics are inefficient, several approaches are then possible:

- The atrioseptostomy [13, 14]
- Implanting an Impella®: it is a pump implanted percutaneously, taking blood from the left ventricle and reinjecting it in the aorta [15, 16]
- Unloading both ventricles by implanting a central double ECLS

5.5 Specifics of VV ECMO Patients

5.5.1 The Avalon® Cannula

This double-lumen cannula placed in the right atrium through the jugular vein must be placed correctly, so that the blood gets out of the cannula in front of the tricuspid valve. To make sure the tip of the cannula is toward the valve, the writing on the cannula must be visible by the nurse. If the writings are toward the patient's neck, then the tip of the Avalon is not in the right direction (Fig. 5.19).

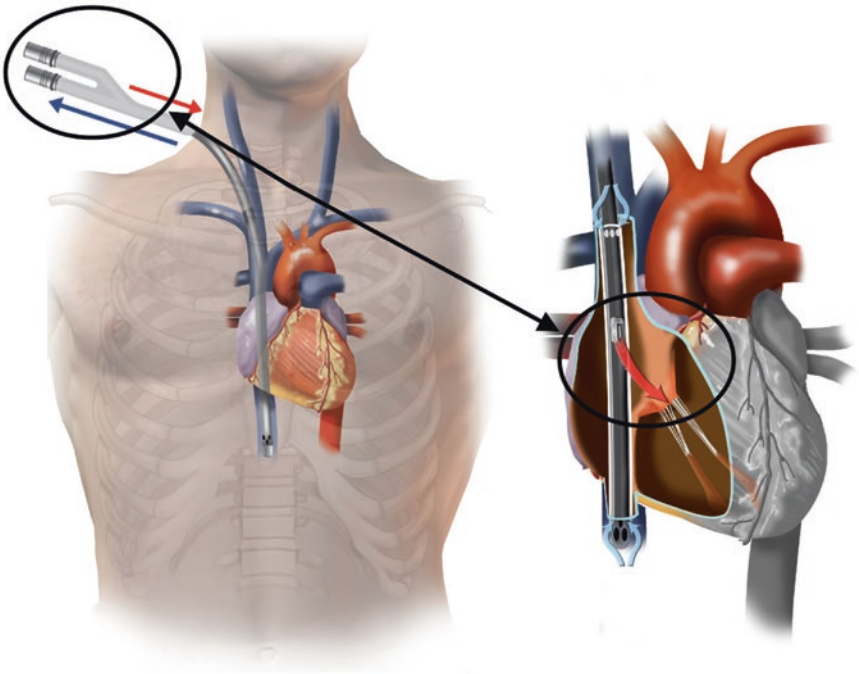

Fig. 5.19 Placement of the Avalon® cannula (Courtesy of Maquet®)

5.5.2 Monitoring of the Patient

For VV ECMO patients, the saturation target is rarely 100%. A saturation of 91% is enough. Most pratients are ventilated on pressure mode, allowing a low and controlled pressure in the lungs. In severe ARDS cases, most patients are completely dependent on the ECMO support and take very low or no volume on the ventilator. Despite these minor volumes, it is of paramount importance that the nurse or respiratory therapist writes down in the patient's chart the volume numbers. If the patient is taking more volume, it could be a sign of lung recovery.

5.5.3 Recirculation

5.5.3.1 Definition

It is a specific phenomenon to VV ECMO implanted in femorojugular and results in an inefficient ECMO run. Oxygenated blood delivered by the ECMO is immediately suctioned by the admission cannula without passing through general circulation. In that case, organs are not efficiently oxygenated, and the patient's status can decline.

It can be caused by:

- Tips of the femoral and jugular cannulas being too close
- Very high flows
- Intrathoracic pressure variations (tamponade or pneumothorax)

5.5.3.2 Monitoring

There is always some recirculation, but it can be diminished by:

- The direction of the ECMO flow: drain from the femoral vein and reinject in the jugular vein.
- A daily monitoring of the cannulas' placement on the X-ray.
- Cannulas of big diameters allow very high flows, but minimize the negative pressure in the leg.
- Strict control of the ventilator settings to avoid variations of intrathoracic pressures

5.5.3.3 « Treating » Recirculation

If, despite taking all the precautions listed earlier, the patient's oxygenation does not improve, several options are still available to bring more oxygen:

- Mobilizing the cannulas
- Switching to a dual lumen cannula (Avalon®): but be careful as these cannulas can be smaller and not allow an ECMO flow above 5 L/min
- Adding a cannula in the other femoral vein

5.6 Specifics of VAV ECMO

VAV ECMO allows a combination of the standard support of a VA and VV ECMO. VAV ECMO is implanted in patients with major lung damage associated with cardiac dysfunction. There is one admission cannula and two reinfusion cannulas: one femoral or jugular for the "VV ECMO" and one femoral for the "VA ECMO". Hence, an additional flow meter must be placed, so that flows in both reinfusion cannulas can be monitored (Fig. 5.20).

Depending on which organ recovers first (the lung or the heart), a clamp is positioned on the appropriate reinfusion cannula to diminish the flow and start weaning.

For example, on the picture below, the patient's heart starts to recover, so that the clamp is placed on the « VA »femoral cannula (Fig. 5.21).

Extreme caution is advised: adjusting the flow with the clamp provokes a partial occlusion of the cannula. If the cannula is completely occluded by the clamp or if

clots and/or fibrin appear on the tubing, do not remove the clampas it may cause major ischemic strokes. The only option then is to remove the thrombosed cannula.

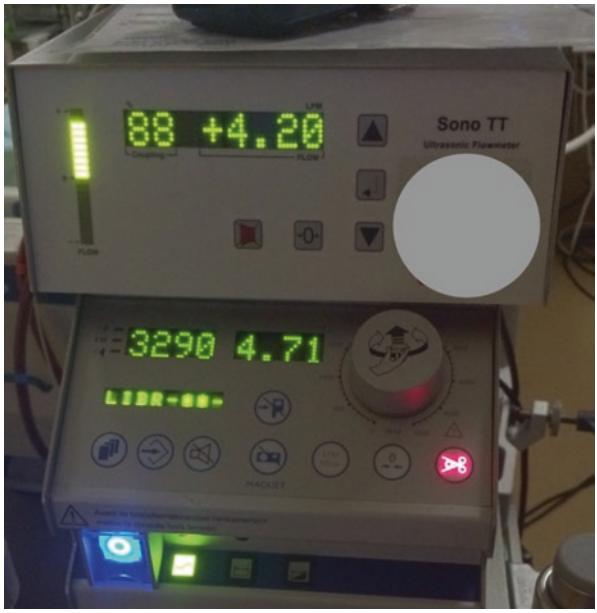

Fig. 5.20 ECMO controller with additionnal flow controller for VAV ECMO patients

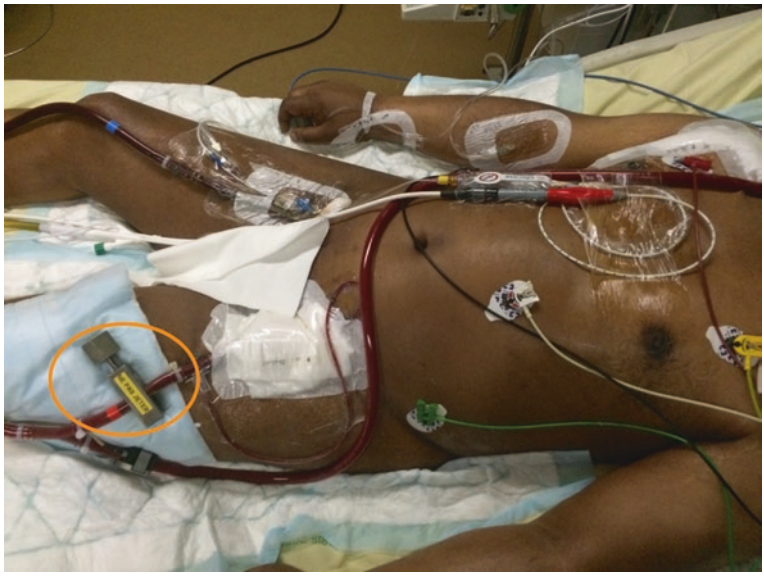

Fig. 5.21 VAV ECMO with partial clamp positionned to adjust the preferential flow

5.7 Troubleshooting

5.7.1 Flow Variations

During an ECMO run, the flow can suddenly vary (e.g., the ECMO flow can pass from 5 L/min to 1.5 L/min in a second). For patients very dependent on their ECMO, this can have major consequences, with an inefficient flow, and the MAP can drop to 45 mmHg and/or the saturation to 75%.

Before assessing the cause and trying to treat appropriately, the nurse should try to stabilize the ECMO flow to avoid clot formation and big hemodynamics changes: the RPM should be lowered until a stable flow is achieved.

For example, if your ECMO had a 5 L/min flow for a RPM of 4500, the nurse may have to turn down the RPM to 3200 to get a stable 4 L/min, even if your MAP is only of 55 mmHg.

Then the nurse should call the doctors, do a complete circuit check to make sure there are no kinks or bleeding. Most probably, these flow variations are due to hypovolemia, and a chattering of the line can be observed: we can see a suctioning phenomenon with a dancing movement of the ECMO tubing. If ECMO pressures are monitored, there also will be a major increase of the PVein.

Be careful, a chattering of line can also be seen:

- When the heart recovers a pulsatility for VA ECMO patients, the ECMO tubings can chatter at the rhythm of the patient's heart.
- If a patient has a balloon pump, the ECMO tubing will chatter at the rhythm of the balloon pump.

In these two cases, the chattering of the line is regular and normal. Chattering becomes a problem when it is associated with flow variations and unstable vital signs.

5.7.2 Decannulation

We saw earlier how to try to prevent inadvertent decannulation, but when it happens, the ICU team must react quickly and efficiently. Unfortunately, any delay even of a few seconds can be lethal to the patient.

Action to be taken: *the 3C rule: CLAMP, Call for help, and Compress.*

1. *Clamp:* It is the first thing to do. In nursing school, nurses are always taught to check the patient first and the machines after. This is one case where this rule does not apply; the priority in case of decannulation is to avoid more blood loss and air embolism. Use the clamps available on the ECMO cart. If unfortunately there is only one clamp available, clamp the reinfusion line to avoid air embolism. And if there are no clamps, clamp the line manually.

2. *Call for help*: It is impossible to manage this situation alone. The quicker you call for help, the safer it is for the patient. All ICU members must know where to find the emergency material or the number to call for the perfusion team to come.
3. *Compress:* The patient can bleed out from insertion point; so, once the lines are clamped, compress firmly.

Of course, after these three steps, all measures to stabilize the patient (CPR, transfusion, setting up a new ECMO) must be taken.

5.7.3 Pump Failure

Pump failure is like decannulation a life-threatening emergency.

Actions to be taken:

- Clamp the cannulas.
- Turn the RPM speed down to zero.
- Take out the pump head out of the motor and place it in the backup pump.
- Start the backup pump (electrically or manually).
- Take off the clamp on the admission cannula first and then on the reinfusion cannula.

Depending on the manufacturer, the backup pumps are manual or electrical. Make sure that all team members know how to transfer the pump head and start the emergency backup pump. Not only initial training but continuous education is also crucial. At least once a year, a training for all team members should be organized.

Usually manual backup pumps have a hand crank. Like we saw in the circuit check, the crank must be placed somewhere near the original pump head, and the nurse must be able to crank "fluently" without any obstacle.

5.7.4 Oxygenator Failure

We discussed throughout the chapter about the different parameters that will allow the team to try to detect early an oxygenator failure:

- Alteration of blood gases without any changes in the ECMO parameters and patient's general status
- Significant rise in the Δp (>20 mmHg/h)
- Presence of numerous clots or an increase of clots and fibrin

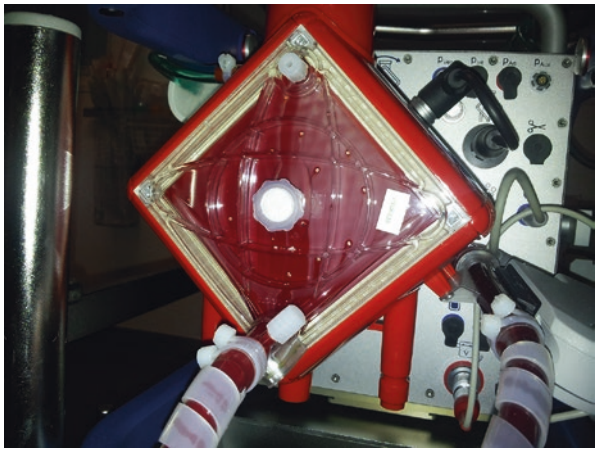

Fig. 5.22 White Veil on the oxygenator of a VV ECMO

In our experience in La Pitié, in some VV ECMO patients infected with the H1N1 virus, a white veil can appear in less than an hour and be also a sign of oxygenator clotting (Fig. 5.22).

When an oxygenator is failing, it has to be replaced. Depending on the team's strategy, two options are possible:

- Change only the oxygenator.
- Change the entire ECMO circuit. We recommend a complete circuit change, especially if one uses circuits with multiple pigtails and stopcocks. In this case, there are probably clots in those connectors too, and a complete circuit change will be safer.

5.8 Psychological Support

Being on ECMO support or having a loved one being implanted with an ECMO is difficult to understand. This device is not well known, and it is a last resort therapy when conventional treatment has failed. Families (and patient if possible) need to be guided: they must understand why the ECMO has been implanted, the adverse events and complications that can occur, and the concept that the ECMO is an emergency device set up to give time to the medical team to assess the options. "The bridge" therapy has to be explained:

- Bridge to recovery: the heart recovers and the ECMO can be withdrawn.
- Bridge to bridge therapy: the patients will be implanted with a VAD. This is considered for patients with a possibility of long-term recovery. It allows the patient to go back home.
- Bridge to transplant.
- A destination therapy: when ECMO is the last resort and is ineffective. A procedure of end-of-life care must then be set up.

An effective, honest, and clear communication has to established, and regular meetings set up to explain the evolution of the patient's medical status. It can be very difficult for the patients or families to understand right away that the device that is saving their loved one's life can also be a source of major complications or lead to death.

Also, staff are exposed to additional stress. ECMO gives an extra workload, and support of patient and family can be time-consuming. Some long or difficult ECMO runs with negative outcomes can discourage team members. An open communication inside the ICU team is of paramount importance, so that everyone accepts the patient's plan of care.

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