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Extracorporeal Membrane Oxygenation for Treating Severe Cardiac and Respiratory Failure in Adults: Part 2—Technical Considerations

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IN THIS SECOND OF 2 articles on the use of extracorporeal membrane oxygenation (ECMO) for treating severe cardiac and respiratory failure in adults, the physiology, technical considerations, and complications of this technique are reviewed. Although ECMO remains a technically and logistically demanding undertaking, recent advances in the design of circuit components, particularly the oxygenator, have improved the ease of use and durability of the technique, such that extracorporeal support can be maintained relatively safely for several weeks.

PHYSIOLOGY OF ECMO

There are 2 basic types of ECMO: venoarterial (VA), which provides support for the heart and the lungs, and venovenous (VV), which provides support for the lungs only.

VA ECMO

With VA ECMO, systemic venous blood drains into the circuit via a cannula placed in the vena cava. This blood passes through the pump and the oxygenator/heat exchanger before returning to the patient via a cannula placed in a large artery (Fig 1). This mode of support is similar to standard cardiopulmonary bypass (CPB) in that both the heart and the lungs are bypassed. Systemic arterial blood flow is the sum of the ECMO circuit flow and any ejection from the left ventricle (LV). Systemic blood pressure is determined by total blood flow and arteriolar tone. Adjusting the flow and F_IO_2 of the sweep gas controls gas exchange by the oxygenator; F_IO_2 determines oxygen tension and gas flow determines carbon dioxide tension.

In the absence of any LV ejection, the patient's systemic arterial oxygen saturation (SaO_2) is determined entirely by the oxygen saturation of blood in the ECMO return cannula, which is normally 100%. However, if there is LV ejection, SaO_2 depends on the relative flow and oxygen saturation of blood from both the ECMO circuit and blood ejected by the LV. This is important in the specific circumstance of severely impaired lung function in conjunction with femoral placement of the ECMO return cannula. In this situation, there is the potential for upper body (coronary arteries, cerebral blood vessels, and upper limbs) hypoxemia because proximal branches of the aorta receive predominantly deoxygenated blood ejected from the left heart. Even in the presence of significant LV ejection, this situation does not arise if pulmonary function is good or the return cannula is placed centrally (either directly into the proximal aorta or into the axillary artery).

Arterial carbon dioxide tension ($PaCO_2$) is determined by the balance between carbon dioxide production and carbon dioxide elimination (by the oxygenator and lungs). In practice, $PaCO_2$ is easily controlled by adjusting the oxygenator sweep gas flow, even in the absence of any alveolar ventilation.

VV ECMO

With VV ECMO, both drainage and return cannulae are placed in systemic veins (Fig 2). Gas exchange can be supported, even in the absence of any pulmonary function, but there is no direct support of cardiac function. (However, cardiac function is often improved with VV ECMO because mechanical ventilation is concurrently reduced and oxygen delivery to the heart is improved.) Fully oxygenated blood from the ECMO return cannula mixes with systemic venous blood, which then passes to the pulmonary artery and through the lungs. Ideally, only deoxygenated systemic venous blood enters the ECMO drainage cannula. However, depending on the positions of the cannulae, a variable proportion of oxygenated blood from the return cannula enters the drainage cannula. This is known as recirculation.

SaO_2 is determined by the oxygen saturation of blood entering the lungs (ie, the mixed venous oxygen saturation [SvO_2]) and by any additional oxygenation of blood that occurs within the lungs. SvO_2 is determined by the relative contributions to

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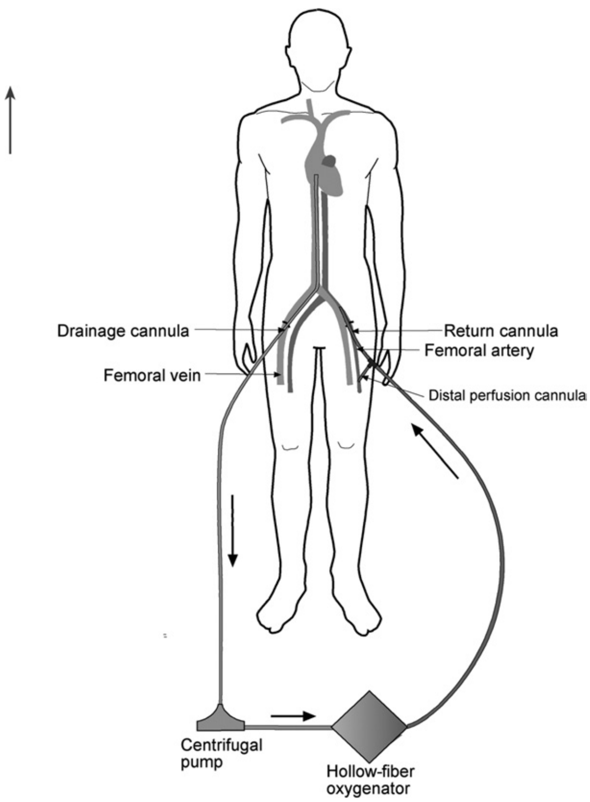

Fig 1. Venoarterial ECMO: the drainage cannula is seen exiting the right femoral vein. The tip of the drainage cannula is in the right atrium. The return cannula is in the femoral artery. A distal perfusion cannula, attached to the return line via a T-connector, is shown. In this particular example, the circuit is comprised of a centrifugal pump and a hollow-fiber polymethylpentene oxygenator with integrated heat exchanger. The direction of blood flow is shown with arrows.

pulmonary blood flow of the ECMO return cannula (oxygenated blood) and the systemic venous return (deoxygenated blood). Recirculation reduces the delivery of oxygenated blood to the pulmonary artery, leading to a reduction in SvO_2. Thus, SaO_2 is determined by (1) ECMO flow, (2) the patient's systemic venous return (ie, his/her cardiac output), (3) the degree of recirculation, (4) the oxygen saturation of systemic venous blood, and (5) pulmonary function. Of these parameters, and in the absence of significant recirculation, ECMO circuit flow is the most important and easily manipulated determinant of SaO_2. If there is little effective pulmonary function, SvO_2 is similar to SaO_2. In the absence of an abnormally elevated cardiac output or a hypermetabolic state, an SaO_2 above 85% can be achieved with VV ECMO, even with minimal or absent pulmonary function. However, unless pulmonary function is relatively good (ie, SaO_2 is significantly higher than SvO_2), an SaO_2 above 95% is rarely achieved.

ECMO CIRCUITS AND EQUIPMENT

An ECMO circuit is comprised of (1) drainage and return cannulae, (2) tubing, (3) blood pump, and (4) oxygenator/heat exchanger. Apart from differences in the cannulae, identical circuits are used for both VV and VA ECMO.

Blood Pump

There are 2 basic types of blood pump: roller and centrifugal. They each have their advantages and disadvantages. Roller pumps have been popular in North America, whereas centrifugal pumps are widely used in Europe, Australia, and New Zealand and are gaining in popularity worldwide.

Roller pumps consist of flexible tubing inside a curved raceway. Rollers mounted on a rotating arm progressively compress a segment of tubing pushing blood ahead of the roller. A roller pump is usually used in conjunction with a blood-filled bladder sited between the drainage cannula and the pump to allow continuous pumping despite changes in the patient's intravascular volume. Blood drains passively into the bladder; if the bladder empties, the pump is shut off by a servo-controlled mechanism, thus preventing the development of high negative pressure in the drainage tubing. With hypovolemia, pump speed and therefore blood flow decrease. Roller pumps are afterload independent. Thus, with VA ECMO, a change in the patient's systemic vascular resistance (SVR) does not influence blood pumping. However, if the return tubing becomes obstructed, high pressure can develop distal to the pump, potentially causing tubing rupture. Because drainage into the bladder occurs under the influence of gravity, roller pumps must be kept below the level of the patient, which is an important consideration when transporting patients on ECMO. With roller pumps, there is a direct relationship between pump speed and blood flow; thus, a flowmeter within the circuit is not required.

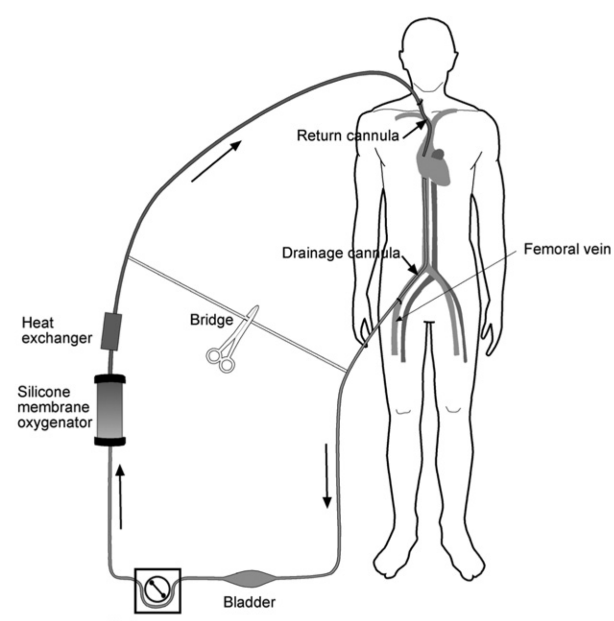

Fig 2. Venovenous ECMO: the drainage cannula is seen exiting the right femoral vein. The tip of the drainage cannula is at the level of the diaphragm. The return cannula is in the right internal jugular vein with the tip just inside the right atrium. In this particular example, the circuit is comprised of a roller pump with bladder, a silicone membrane oxygenator, and a separate heat exchanger. A bridge is also shown.