How to face the challenge: contrast enhanced computed
tomography scanning of patients under ExtraCorporeal
Membrane Oxygenation - ECMO.

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Learning objectives

1. To have an understanding of the clinical background of patients in need of extracorporeal membrane oxygenation (ECMO).
2. To explain and review the function and different types ECMO systems.
3. To discuss the problems, difficulties and solutions of achieving good quality contrast enhancement in CT examinations with EMCO.
4. To demonstrate both successful and problematic clinical cases from our centers experience.
5. To provide a schematic workflow with tips and tricks derived from our multidisciplinary team experience in order to achieve a higher success rate of good diagnostic exams.
Fig. 1

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Background

Introduction

Extracorporeal Membrane Oxygenation (ECMO) is a procedure where a critically ill patient gets life support from a modified heart lung machine which can provide respiratory, circulatory or both respiratory and circulatory support. The clinical condition of these patients often requires CT examinations. However CT scanning in these complex patients brings additional risks to the patient such as transport and CT table motion with connected ECMO equipment and critical catheters and tubing.

Contrast enhanced CT in ECMO patients is very challenging because the ECMO machine fully or partially takes over heart function resulting in abnormal flow, dilution and timing of the contrast media. This abnormal flow can result in failed scans. To justify the risks of patient transport and the CT scan itself a good success rate of the contrast enhanced CT exam is required.

An ECMO support circuit oxygenizes and decarboxylases venous blood. Blood is drained with a large bore cannula in a central vein, and is actively pumped (up to 7 l/min) through the oxygenator. The blood can again be returned in a large central vein, and then is called veno-venous ECMO (vvECMO). vvECMO is deployed for pulmonary support, in which, theoretically it can replace the entire lung function. On the other hand, blood can also be returned in a large artery, and then it is called veno-arterial EMCO (vaECMO). Often, this type is used for circulatory support. vaECMO can replace the entire heart and lung function.

ECMO has been deployed for more than 40 years, first as a therapeutic option for circulatory shock and later also for the worst cases of acute respiratory distress syndrome (ARDS). ECMO for respiratory support was found not to be superior to conventional treatment in two randomized controlled trials in the nineteen-nineties.\textsuperscript{1,2} Consequently, its use has long been restricted to neonates and small children. Due to major technological improvements in ECMO machines and catheters, ECMO has regained interest and the number of published case series has increased since the beginning of this century. Especially during the H1N1 pandemic, a dozen case series of patients who failed on conventional ventilation and were saved by ECMO therapy. ECMO has additionally been introduced in the emergency department for the purpose of extracorporeal cardiopulmonary resuscitation (ECPR) in patients with sudden cardiac death.

Indications and complications
The extracorporeal life support organization (ELSO) has the following indications for ECMO:

**Respiratory failure**

- Neonates with severe respiratory failure, refractory to maximal medical management, with a potentially reversible etiology.
- Pediatric: While no absolute indicators are known, consideration for ECMO is best within the first 7 days of mechanical ventilation at high levels of support.
- Adults:
  1. Hypoxic respiratory failure due to any cause (primary or secondary) should be considered when the risk of mortality is 50% or greater, and is indicated when the risk of mortality is 80% or greater.
  2. CO2 retention on mechanical ventilation despite high Pplat (>30 cm H2O)
  3. Severe air leak syndromes
  4. Need for intubation in a patient on lung transplant list
  5. Immediate cardiac or respiratory collapse (PE, blocked airway, unresponsive to optimal care)

**Cardiac failure**

- Pediatric
  1. Early postoperative cardiac failure in the operating room (unable to come off bypass)
  2. In the ICU: the severity defined by pressor and inotropic requirement, metabolic acidosis, decreased urine output for 6 hours.
  3. Cardiac arrest from any cause: with response to CPR but still unstable and no response to CPR direct massage underway for 5 minutes
  4. Myocardial failure unrelated to operation: myocarditis, myocardiopathy, toxic drug overdose.
  5. Elective support through high risk catheter procedures
- Adult with cardiogenic shock
  1. Inadequate tissue perfusion manifested as hypotension and low cardiac output despite adequate intravascular volume.
  2. Shock persists despite volume administration, inotropes and vasoconstrictors, and intraaortic balloon counter pulsation if appropriate.
  3. Typical causes: Acute myocardial infarction, Myocarditis, Peripartum Cardiomyopathy, Decompensated chronic heart failure, Post cardiotomy shock.
4. Septic Shock is an indication in some centers.

ECMO will not heal the heart or lungs but gives them time to recover and serves as a bridging therapy instead of a curative therapy. The ECMO treatment can buy time to:

- Naturally recover or give time to other treatments to take effect. e.g acute myocardial infarction after revascularization, Myocarditis, Postcardiotomy
- Allow clinicians time for additional tests make and decisions for the definitive treatment plan. e.g. implantable circulatory support: Ventricle Assist Device, Total Artificial Heart
- Wait for a donor organ to be available for transplant. e.g. unrevascularizable acute myocardial infarction, chronic heart failure
- Decrease the use of damaging ventilator settings or harmful medications.

General complications in patients under ECMO support are:

- Adjacent or distal hemorrhagic complications: (including intracranial hemorrhage and/or infarction).
- Infectious complications.
- During vaECMO support, the arterial cannula may be occlusive, and cause distal ischemia.
- Mechanical complications: pump malfunction, cannula malposition or dislocation
- Air or distal thromboembolism and stasis thrombus in access vessels.

Common reasons for CT-scan are assessment of the pulmonary function during vvECMO, Abdominal ischemia or evaluation of (pulmonary) embolism during vaECMO, Intracerebral ischemia and/or bleeding during vaECMO and vvECMO.
Fig. 1

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**Fig. 2:** Graphic presentation of an ECMO circuit with its components. Blood circulates under the patients own blood pressure or is aided and controlled with a pump. A blender provides an air-oxygen gas mixture to the oxygenator-heat exchanger where the fresh gas passes venous blood along a semipermeable membrane allowing oxygen uptake in the blood and CO2 dissipation through the gas. Additionally fluids and heparin access points are needed with the tubing and insertion cannulas.

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Fig. 3: Example of a standard pediatric ECMO installation at Erasmus MC. The patients treated with ECMO often have a large amount of additional medical devices like connected to them like i.v. pumps and catheters. Transporting these vulnerable patients to the CT suite and on to the CT table consists of a considerable risk in case of technical failures or cannula dislocations.

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Fig. 5: The local trend in ECMO case numbers at the Erasmus Medical Center Rotterdam. Erasmus MC follows the international trend of an increasing number of ECMO support cases. In most recent years ECMO in cardiac resuscitation (ECPR) was introduced which also shows an increasing trend.

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**Fig. 6:** Indication distribution for adult patients who received vvECMO or vaECMO in ErasmusMC.

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Fig. 4: The inventory of the international ELSO registry shows an increase in the number of ECMO performing centers and the number of ECMO cases. Illustrating the increased use of ECMO trend over the last 25 years.

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Findings and procedure details

ECMO configurations

Although there are a wide variety of ECMO systems and cannulas in use they can be classified by the veno-venous, veno-arterial or arterio-venous set-up together with the cannula entry points and tip locations. The cannulas have typically large inner & outer diameters to allow high flow and pressure management.

*Femoroatrial vvECMO:*

femoral vein drainage cannula and right atrial return cannula.

*Femorofemoral vvECMO:*

return and drainage cannulas placed in femoral veins.

*Dual-lumen single cannula vvECMO:*

via the right internal jugular/femoral vein with the tip in the IVC/SVC.

*Peripheral vaECMO:*

peripheral venous drainage cannula and peripheral arterial return cannula.

*Central vaECMO:*

direct right atrial drainage cannula and ascending aorta or carotid return cannula.

Occasionally a second drainage cannula is required for to obtain higher flow creating a vvaECMO or vvvECMO. With these systems blood is drained both caudal and cranially from the heart.

*Femorofemoral avECMO:*

Is a pumpless system which drains in an artery (femoral) and returns in a vein(femoral)

This option is only usable with sufficient native patient circulation and allows a small amount of oxygenation but predominantly CO2 removal.
CT risks and challenges

Patient motion

Even with extensive heparine treatment blood clotting is a risk. Moving a patient can dislocate existing cloths in the tubing of the ECMO circuit or in the patients entry and exit vessels resulting in embolisms. Patient movement also has a risk of causing tubing and/or cannula dislocations. Therefore motion of the patient should be minimized.

Clear communication of the multidisciplinary team before and during the transfer of the patient on the CT table can avoid unnecessary repositioning of the patient and minimize the risk of cannula dislocation. Depending on the type of ECMO tubing and cannulas the body part to be scanned and the expected table motion range and speed a head first or feet first approach can make a big difference. Similar if the ECMO pumps need to be besides the scanner table or can be put on the scanner table can have critical benefits or drawbacks for the table motion during the scan. These decisions should be clear prior to putting the patient on the CT table.

Every time the patient is moved it should be communicated to the perfusionist and he/she should confirm motion is allowed.

Contrast administration

A dedicated individualized contrast administration protocol is required for every single patient. Standard protocols can result in failed scans because contrast may be siphoned off by the ECMO disrupting normal timing and distribution of contrast.

Key information points to determine a contrast protocol:

- Which body part (or circulation part) needs to be visualized best
- What kind of scan do we need arterial or venous or both.
- What kind of ECMO is in use.
- Where are the drainage and input cannulas located
- Does the patient have normal, reduced or absent cardiac function
- Is it possible to temporary reduce ECMO flow during the CT
- Is it possible to scan at reduced kVp settings e.g 80kVp
- Is it possible to scan with dual energy and reconstruct reduced keV settings e.g. 40keV
- Where can we potentially inject contrast:
  1. Inferior circulation e.g. iv. in leg.
  2. Superior circulation e.g. iv. in arm.
3. Directly on the ECMO circuit e.g. arterial input. (what will then be the flow of the ECMO in ml/sec.?)

vvECMO

Because vvECMO is used for pulmonary and not circulatory support you can expect normal flow by the patient's own heart. U can use normal protocols for arterial-venous head, thorax, abdomen or leg CT.

Pitfall for vvECMO is contrast administration via the same route as the location of the drainage cannula. If contrast is injected at the foot while drainage is done in the inferior vena cava the contrast will be siphoned off into the ECMO first before reaching the heart. There might be more dilution of the contrast than expected in this case.

To build in additional safety in the protocol use low kVp single energy or low keV dual energy scans to obtain maximum contrast enhancement. In addition ECMO flow may be reduced if allowed by intensivist/perfusionist.

vaECMO

To visualize the lung circulation in patients with some remaining heart function a good option is to reduce flow or temporarily suspend the ECMO if allowed. Then give contrast via the superior venous circulation (opposite to drain circulation).

In the abdomen however this might not work. The contrast pumped through the heart into the aorta will encounter retrograde flow from the arterial input of the ECMO. Depending on the balance between native flow and ECMO flow the contrast might not reach the abdominal or distal aorta and only follow the lees resistant path into the head and arms. Also the legs cannot be visualized in this situation. A good option for the abdomen and legs in a patient with remaining heart flow is to inject into the circulation of the drainage cannula e.g. in the feet. In this way the contrast will be siphoned off into the ECMO and directly input in the vessels of interest (Abdominal and leg arteries). Because the arterial input will encounter counter pressure from the heart in this case the ECMO flow should not be reduced in order to get the contrast more proximal into the aorta above the mesenteric artery.

Another option is to directly connect contrast to the arterial input tubing of the ECMO in our experience we have good results when we calculate the ECMO flow in ml/sec. and then inject contrast at a ratio of 1:10 to 1:20 of the ECMO flow.

- 1:20 for CTA80kVp or dual energy low keV
- 1:15 for CTA 100kVp
• 1:10 for CTA 120kVp

There are additional risks with direct injection at the ECMO input:

• Microbiological contamination the tubing connection.
• Operator induced air embolism.
• Pressure failure off the connection at high contrast flowrates/viscosity or malposition of the 3-way connection.

To minimize risks the connection should be done by the experienced perfusionist and not the radiographer. Contrast should be warm to minimize viscosity and low kVp should be used if possible to reduce flow and pressure.

For every contrast enhanced ECMO CT it is good to have a 2nd back-up scan already preprogrammed. In case of an initial scan where contrast timing/enhancement was insufficient the back-up scan can be started at will to try and get a better later phase either still in first pass or after recirculation.
Fig. 7: Graphical display of: femoro-atrial vvECMO

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Fig. 8: Graphical display of: femoro-jugular vvECMO

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Fig. 9: Graphical display of: double lumen-single cannula vvECMO

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Fig. 22: Graphical display of: central vaECMO

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**Fig. 13:** Graphical display of: peripheral vaECMO

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Fig. 10: Graphical display of: femoro-femoral avECMO

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**Fig. 14:** Erasmus MC contrast chart for pulmonary CTA in patient with vaECMO either with or without residual cardiac output.

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**vaECMO with residual cardiac output**

- CTA thoracic aorta - head - neck by antegrade flow through heart
  - Use reduced kVp or dual energy low keV scan.
  - Inject contrast in superior circulation (arm or jugular)
  - Reduce ECMO flow if allowed
  - Real time timing in ascending aorta
  - Have a 2nd backup scan ready to repeat immediately or within a few seconds if contrast timing seems incorrect at initial scan.

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**Fig. 23:** Erasmus MC contrast chart for thoracic aorta-head-neck CTA in patient with vaECMO and residual cardiac output.

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Fig. 24: Erasmus MC contrast chart for thoracic aorta-head-neck CTA in patient with vaECMO and without residual cardiac output.

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Fig. 15: Erasmus MC contrast chart for abdomen-leg CTA in patient with vaECMO and without cardiac output.

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**Fig. 16:** Erasmus MC contrast chart for abdomen-leg CTA in patient with vaECMO and with residual cardiac output.

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Fig. 11: Erasmus MC contrast chart for patient with vvECMO or avECMO without pump.

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CASE 1: veno-venous-ECMO

- Patient on vvECMO support due to legionella pneumonia.
  - Drainage inf. vena cava-right atrium
  - Input right common iliac artery
- Clinical question: scan CTA thorax abdomen
  - Bleeding focus?
  - Bowel ischemia?
- Contrast input – jugular PICC line at 3.5ml/s
  - ECMO on normal flow
  - Timing – bolus tracking ascending aorta

Scan without contrast (left) showing position of:
- Venous input cannula tip
- Venous drainage cannula tip
Scan with contrast (right) showing:
- Retrograde enhancement of v. cava inferior because ECMO was still on full flow.
- Contrast blushes / bleed focus

Because normal cardiac circulation of patient, pulmonary vessels, heart and aorta enhance normally.
There is no blood entering the heart from cava inferior causing less dilution of contrast than normally.
Together with low kV good enhancement is achieved.

Fig. 12: CASE 1: Example of vvECMO thorax abdomen CTA

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Fig. 17: CASE 2: example of vaECMO thorax abdomen CTA

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**Fig. 18:** CASE 2: example of vaECMO thorax abdomen CTA

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CASE 3a: veno-arterial-ECMO

- Patient on vaECMO support with remaining native cardiac output.
  - Drainage infra cava-right atrium
  - Input right common iliac artery
- Clinical question: scan thorax abdomen
  - Bowel ischemia?
  - Pneumatosis intestinalis?
  - Pleura fluids?
  - Ascites?
- Contrast input – i.v. in feet with reduced ECMO flow
- Timing – bolus tracking descending aorta

Fig. 19: CASE 3a: example of vaECMO abdomen CTA Example of a failed scan. The main goal was to get good contrast attenuation of the mesenteric arteries. Because the contrast was administered in the feet all contrast was drained into the ECMO and there was no first pass through the heart during the bolus tracking and the eventual manual start of the scan was too late. All contrast was bypassed through the ECMO and injected into the iliac artery. Because the ECMO flow was reduced the retrograde contrast flow in the aorta encountered resistance by the residual flow of the heart of the patient.

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CASE 3b: veno-arterial-ECMO

- Second attempt now with contrast input – i.v. in arm with reduced ECMO flow
- Timing – bolus tracking descending aorta

First pass contrast now passed through the heart and pulmonary circulation. But stops at the renal arteries.

The second attempt now with contrast administered in the arm shows an opposite effect.

First pass contrast now does not go through the ECMO but through the heart and encounters resistance from the ECMO input at the level of the renal arteries.

In retrospect the first scan would probably have been successful if injected in the feet but without reducing the ECMO flow. Together with a timing at the level of the abdomen instead of the thorax. Then the stronger input would have passed the contrast beyond the superior mesenteric artery.

Fig. 20: CASE 3b: example of vaECMO abdomen CTA This example shows that in a vaECMO patient with residual cardiac function and drainage in the inf v.cava contrast injection from superior together with reduced ECMO flow can provide good contrast in the heart and pulmonary circulation but arterial abdominal contrast might be compromised. For abdominal CTA a better option is either inferior contrast administration or direct contrast administration on the arterial input of the ECMO without reduced ECMO flow.

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CASE 5: veno-arterial central ECMO

- 6 month old child on vaECMO support virtually without native cardiac output.
  - Drainage inf. vena cava-right atrium
  - Input ascending aorta
- Clinical question: anatomy/patent coronary arteries?
- Contrast input:
  - Direct on the arterial input of the ECMO and ECMO on full flow
  - Contrast flow 1:20 of ECMO flow scan at 80kV

Be careful and aware that injecting at arterial input has an increased risk of operator induced air embolism.

Fig. 25: CASE 5: Example of central vaECMO in a child for coronary CTA

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**Fig. 21:** CASE 4: Example of Thorax CTA in patient with vaECMO and no residual circulation.

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Conclusion

ECMO is a procedure where a critical patient gets life support from a modified heart lung machine which can provide respiratory, circulatory or both respiratory and circulatory support.

CT scanning brings additional risks to the patient such as transport and table motion with connected catheters.

The ECMO machine fully or partially takes over heart function resulting in abnormal flow, dilution and timing of the contrast media.

A multidisciplinary team approach is needed to make an individual optimized and save scan strategy for every patient.
Fig. 26: Using a time out procedure prior to transfer of the patient to the CT table can structure the scanning process of these difficult cases. Having an organized and standard procedure can reduce the chance of complications and increase the chance of a successful scan.

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