

## **Abstract**

Acute right ventricular (RV) failure following massive pulmonary embolism (PE) can have significant haemodynamic consequence and is the mode of death. Temporary mechanical circulatory support can provide tissue perfusion required while thrombectomy or lysis-aimed therapies act to relieve thrombotic obstruction. Venous-arterial extracorporeal membrane oxygenation (V-A ECMO) has conventionally been the first line MCS. A more selective approach to RV support has been advocated in the form of extracorporeal right ventricular assist device (RVAD) as it mitigates some of the shortcomings of V-A ECMO. We present the first case series of four patients who received fully percutaneous RVAD, with integrated oxygenator forming an Oxy-RVAD, for selective right heart support following massive PE, including the application of single access dual-lumen right atrium to pulmonary artery cannula. All patients achieved RV recovery and were successfully weaned from oxy-RVAD support within 5-10 days demonstrating feasibility of selective percutaneous right heart support in managing these challenging patients.

**Keywords:** Dual-lumen cannula, percutaneous, right ventricular assist device, pulmonary embolism

## Introduction

Acute right ventricular (RV) failure with resulting low systemic output is the leading cause of death in patients with high-risk pulmonary embolism (PE). About 30% of patients with PE have RV dysfunction, with an associated mortality of 25-40%. Mortality increases to 65% if there are signs of haemodynamic compromise such as tachycardia, hypotension, or syncope (1).

According to the most recent European Society of Cardiology guidelines for management of acute PE, mechanical circulatory support (MCS), of which only veno-arterial extracorporeal membrane oxygenation (V-A ECMO) and Impella RP (Abiomed) are mentioned, is reserved for those with high risk PE and circulatory collapse or cardiac arrest (2). However, the optimal treatment strategies remain unclear and good quality evidence to guide the use and timing of MCS is lacking.

There are very few reports of MCS for PE management. In a recent systematic review, of 181 patients with PE requiring MCS, most were managed on V-A ECMO (164 patients). Of these, 122 (74%) patients weaned from V-A ECMO, and 120 (73%) survived to hospital discharge (3). In this review, only 17 cases of temporary right ventricular assist device (RVAD) comprising 8 Impella RP and 9 RVAD variations (2 percutaneous and 7 central) were reported. All 17 RVAD patients were successfully weaned, with 94% (8/8 Impella RP and 8/9 RVAD) surviving to hospital discharge.

Most RVADs are surgically implanted with central cannulation of the right atrium (RA) and main pulmonary artery (PA) and are therefore rarely used. When the indication is massive PE with concomitant thrombolytic therapy, the risk of bleeding with sternotomy and open surgical device placement is very high. Percutaneous devices provide the opportunity for early intervention in RV failure without the need for surgery

and its associated complications. Options for peripheral temporary RV support are increasing and include peripheral V-A ECMO, Impella RP, and RVAD with two percutaneous cannulae or with novel devices such as the ProtekDuo cannula (TandemLife, Pittsburgh, PA).

The ProtekDuo is a single access dual-lumen, cannula placed percutaneously via the right internal jugular vein (RIJV), that comes in 29Fr and 31Fr diameters. When coupled with an external centrifugal pump, it can produce high blood flows (4-5L/min), with drainage from the RA and return to the PA. It also offers the option of connecting an oxygenator into the circuit becoming an oxy-RVAD, also known as veno-pulmonary extracorporeal membrane oxygenation (V-P ECMO). It is a multipurpose cannula that can be used in various other configurations, such as left ventricular and biventricular assist devices, when combined with an Impella device or other LVADs, or when combined with another drainage cannulae, can form venovenous-pulmonary (VV-P) ECMO or veno-venopulmonary (V-VP) ECMO (4).

We present a case series of four patients from our MCS centre who had percutaneous oxy-RVAD for management of RV failure secondary to PE, including the use of the ProtekDuo. All patients were referred via the respiratory ECMO pathway in our high-volume centre which manages around 150 veno-venous ECMO cases and 50 V-A ECMO cases per year. Ethical approval was not required for this case series. Written informed consent for the publication of anonymised clinical information was gained from patients.

### **Case 1**

A 30-year-old man with a history of anabolic steroid use had a spontaneous haemorrhage of a hepatic adenoma. He had selective hepatic artery embolisation, a

short 2-day stay on the intensive care unit (ICU) and was discharged. He re-presented 1-week later with abdominal pain and haemodynamic compromise. Computerised tomography pulmonary angiogram (CTPA) showed a large peri-hepatic haematoma, a near-occlusive thrombus of the right iliac vein and inferior vena cava (IVC), and large emboli in both main PA. Echocardiography demonstrated severe RV dysfunction with an underfilled LV in keeping with massive PE. He had systemic thrombolysis, an IVC filter, and catheter-directed thrombolysis. However, he developed acute cardiac failure with worsening lactatemia, increasing inotropic requirements, type 2 respiratory failure (T2RF), secondary anuric renal failure and ongoing liver dysfunction. He was referred to our MCS centre. He was transferred to the intervention suite of the local centre where he was intubated and ventilated for worsening respiratory failure. V-A ECMO was considered due to the clot burden and cardiovascular instability therefore the IVC filter was removed and left femoral artery sheath inserted (in case peripheral V-A ECMO cannulation became necessary). A single access dual-lumen RA to PA cannula was inserted under fluoroscopic and transoesophageal echocardiographic (TOE) guidance (Figures 1 and 2A). The lumens of the dual-lumen cannula were connected into our standard ECMO circuit with integrated oxygenator providing oxy-RVAD support (Cardiohelp with integrated HLS 7.0 oxygenator; Fig 3A; Table 1). There was immediate improvement in oxygenation and systemic perfusion. He was transferred on mobile MCS to our centre. His liver function improved after establishing oxy-RVAD support, but he required haemofiltration for most of his ICU admission. After 10 days on oxy-RVAD support, the PEs resolved on repeat CTPA, and echocardiogram showed good RV function on a weaning study. He was taken off MCS support and after 2 weeks no longer required haemofiltration. He was discharged 3 weeks later.

He made a complete recovery with normal echocardiographic RV function and normal PA pressures 6-months later.

## **Case 2**

A 22-year-old female collapsed at home following a 2-day history of abdominal pain. On arrival of the helicopter emergency medical services she was in pulseless electrical activity (PEA) cardiac arrest. She had a 26-minute downtime before return of spontaneous circulation (ROSC). An electrocardiogram showed right bundle branch block, and ultrasound scan showed fluid in the pelvis. She was thought to have an ectopic pregnancy. After intubation and stabilisation with blood and antibiotics she was transferred to the local emergency department. CTPA showed extensive bilateral PE in the lobar, segmental and subsegmental branches, and echocardiogram showed isolated RV dilatation and dysfunction. She was given systemic thrombolysis. She had refractory cardiac arrest with total 50-minutes downtime and developed cardiogenic shock with severe lactic acidosis, requiring aggressive fluid resuscitation, moderate doses of vasopressors and inotropes. Following referral for MCS, she was transferred to the local intervention suite where a single access dual-lumen RA to PA cannula was inserted and connected to an ECMO circuit establishing oxy-RVAD support (Figure 2B, Table 1). Due to the lack of vascular surgical support in the referring centre, thrombolysis, and isolated RV failure, percutaneous oxy-RVAD was deemed the most appropriate mode of MCS for this patient. In addition, she had minor bleeding complications following the thrombolysis (Table 1); a single access jugular venous cannula minimised the risks of bleeding from dual site and arterial cannulation if V-A ECMO was considered. Heparin was not started initially, and the coagulopathy was corrected with blood products. She was transferred to our centre where inhaled nitric oxide (iNO), a second vasopressor and haemofiltration was started. Despite ongoing

coagulopathy, heparin was started for the PE and oxy-RVAD. Repeat echocardiogram showed ongoing severe RV dysfunction and underfilled LV, which improved after increasing the oxy-RVAD blood flow to 4.5L/min. She was weaned off all vasoactive agents by day 2, off iNO by day 3 and repeat echocardiogram on day 4 showed normal RV size with good function on the weaning study. She was decannulated successfully from the oxy-RVAD on day 5. Unfortunately, despite improvement in her RV failure, a repeat CT brain on day 7 demonstrated bilateral intracranial haemorrhages, severe hypoxic brain injury, and signs of imminent coning. The intracranial haemorrhages and hypoxic brain injury are likely multifactorial: secondary to the coagulopathy following thrombolysis, the DIC due to initial insult and long cardiac arrest time. She had minor ongoing bleeding complications whilst on oxy-RVAD but the benefit of anticoagulation outweighed the risks. She did not meet criteria for brain stem death and ICU care was withdrawn on day 9.

### **Case 3**

A 64-year-old male who initially presented with H1N1 influenza and staphylococcus aureus bacteraemia to his local hospital, was treated with antimicrobials and high-flow oxygen. On admission day 6 he had a PEA arrest, with an 8-minute downtime and was intubated and ventilated. Bedside echocardiogram showed severe RV dilatation and failure. He was presumed to have a PE and received systemic thrombolysis. On ICU, a repeat echocardiogram showed a low cardiac index with worsening T2RF. He was managed conventionally for acute respiratory distress syndrome (ARDS). RV failure persisted and he was referred 2-days post-arrest for MCS. He was transferred to the local intervention suite where a single access, dual-lumen RA to PA cannula was inserted (Figure 2C) and connected to an ECMO circuit forming the oxy-RVAD. Once established on the oxy-RVAD, ventilation and vasotropic requirements

significantly reduced. He was transferred on mobile-MCS to our centre for ongoing management. CT scan confirmed large left-sided PE and dense consolidation in both bases in keeping with ARDS secondary to H1N1. Inotropes were weaned off by day 1 following oxy-RVAD. His admission was complicated by gastrointestinal bleeding, and multi-organ failure (MOF) requiring haemofiltration. The weaning study on day 5 showed a non-dilated RV with preserved function and he was separated from oxy-RVAD support. Due to ongoing bleeding and difficulties with anticoagulation, he had an IVC filter inserted on day 8 as well as gastric artery embolisation. On day 9, he was repatriated to his local hospital for ongoing management of ARDS, however he died 2 weeks later due to ongoing MOF.

#### **Case 4**

A 45-year-old female undergoing in-vitro fertilisation therapy outside the United Kingdom developed ovarian hyperstimulation syndrome and was admitted with an ectopic pregnancy requiring bilateral salpingectomy. She re-presented to hospital 10-days later following PEA cardiac arrest. She had a total downtime of 20-minutes before achieving ROSC. On arrival to her local hospital, she was intubated and ventilated and required volume resuscitation. Echocardiogram showed a dilated RV, and CTPA confirmed bilateral large PE with a small right-sided pulmonary infarct. She had systemic thrombolysis but had increasing adrenaline requirements and was referred for MCS. She was transferred by ground transport to our centre and taken straight to the intervention suite where she had a percutaneous oxy-RVAD with conventional cannulation: Biomedicus Multi-stage 25Fr drainage cannula in the right femoral vein, and Biomedicus 23Fr single-stage return cannula via a left IJV sheath and tip in the right PA (Figure 2D, and 3B – the figure shows RIJV placement which is the conventional approach). The left IJV was used as high dose adrenaline was infusing

via the RIJV central line. Insertion via the left IJV is more convoluted through the innominate vein but is possible with the use of fluoroscopy and a skilled operator. The cannulae were connected to a standard ECMO circuit. After 12 hours on oxy-RVAD support and haemofiltration, her metabolic acidosis had normalised, and inotropes were weaned off. She had some bleeding complications from her genitourinary and gastrointestinal tract and anticoagulation was intermittently stopped whilst remaining on the oxy-RVAD. By day 8 oxygen gas flow was weaned off and to reduce anticoagulation requirements, the oxygenator was removed from the circuit forming an RVAD. Milrinone was used to facilitate weaning from the RVAD and she was successfully decannulated on day 10. Due to ongoing bleeding she had an IVC filter placed on day 12 and was started on prophylactic-dose anticoagulation. Echocardiography on day 19 showed her RV had returned to normal size and function. A CT head showed several areas of patchy ischaemia and watershed infarcts. She was repatriated to her local hospital, for neurological and physical rehabilitation. She made a good recovery and was discharged from hospital, returning six weeks later to have her IVC filter removed.

## **Discussion**

There is limited literature regarding selective RVAD support for acute RV failure secondary to PE. This is the first case series to present the use of fully percutaneous RVAD in this setting. In three cases we applied a single access dual-lumen RA to PA cannula and one case received percutaneous RVAD with dual site cannulation. All patients were successfully weaned from MCS over a short time (5-10 days) with good short term RV recovery. This adds to the existing encouraging reports for the use of single access dual-lumen RA to PA cannula for RV failure in other situations including

following placement of durable LVAD (5), RV infarction (6), severe pulmonary hypertension, and post-cardiotomy cardiogenic shock (7). Another group have recently used a single access, dual-lumen cannula in the management of ARDS due to COVID-19 pneumonitis in 80 patients, allowing for early extubation and ambulation with good outcomes (8). Our experience supports these reports that single access dual-lumen RA to PA cannula RVADs are safe and effective for refractory RV failure and appears to have an improved weaning profile compared to central RVAD support. All our cases had systemic thrombolysis prior to initiation of oxy-RVAD, similar to other case reports where MCS is predominantly a rescue therapy (3). All our patients had the advantage of percutaneous cannulation whereas most cases in the literature were cannulated centrally often following sternotomy for embolectomy. We, and one other group, describe the use of percutaneous RVAD for management after massive PE with good outcomes (9).

The decision regarding which MCS device for PE-associated RV failure can be challenging. V-A ECMO bypasses the entire pulmonary circulation and allows time for the thrombi to recannulate or dissolve. Oxy-RVADs and Impella RP temporarily bypass the failed RV and allow for the right heart to improve, but unlike ECMO does not bypass the pulmonary circulation where thrombus may still reside, and therefore may not be the best mode of support for extensive or completely occlusive PE. In our case series all patients had isolated RV dysfunction hence selective RVAD support was chosen. If the patients had LV dysfunction at presentation or later developed LV impairment RVAD support would not be the optimal mode of MCS and V-A ECMO should be considered. The use of the single access dual-lumen RA to PA cannulation provides an additional beneficial option for dynamic ECLS should biventricular support be required at initiation or subsequently in the patient course. For instance, VV-A

ECMO can be provided with drainage from both lumens of the dual-lumen RA to PA cannula and return via an arterial cannula, providing additional LV offloading due to PA drainage. Switching the blood flow direction within the dual lumen cannula can then provide isolated RV support (10). An additional venous drainage cannula can provide a V-VP ECMO configuration, and changing both lumens of the DLC to return lumens can provide V-VP ECMO with increased oxygenation and flow up to 7L/min (4, 11).

For patients with isolated RV failure secondary to PE or other causes, advantages of RVADs are directly reduced RA pressures, unloading the dilated RV, increased mean PA pressures and increase LV preload. Specific to the PE sub-group, two-cannulae RVAD or single access dual-lumen RA to PA cannulae percutaneous RVAD gives the option of incorporating an oxygenator into the circuit to become an oxy-RVAD, an option that is not applicable to microaxial pumps such as the Impella RP. This provides the added advantage of supplying highly oxygenated blood through the pulmonary circulation, reversing hypoxic pulmonary vasoconstriction (HPV) and reducing pulmonary shunt fraction which are important in the pathophysiology of PE. In patients with isolated RV dysfunction, with flow through the pulmonary circulation, oxy-RVAD may also prevent the increase in LV afterload that occurs with peripheral V-A-ECMO. However, there is speculation that in the presence of LV dysfunction of an almost occlusive proximal PE where there is minimal flow through the pulmonary circulation, V-A ECMO may have an advantage over oxy-RVAD.

The benefits of percutaneous oxy-RVAD over V-A ECMO include i) absence of arterial cannulation and therefore avoidance of vascular complications which often require surgical management, ii) avoiding the increased bleeding risk associated with arterial

cannulation, particularly in the context of therapeutic anticoagulation (in our centre we aim for Anti-Xa levels of 0.3-0.5U/ml) iii) highly oxygenated blood flow through the pulmonary circulation, reducing HPV, pulmonary vascular resistance and RV pressures, aiding RV recovery and iv) increased LV preload improving systemic circulation and perfusion. Further benefits of single access dual-lumen RA to PA over standard percutaneous two-cannula RVAD includes i) need for only a single cannulation which can provide almost equal blood flow as a two-cannulae technique ii) improved ability to mobilise and engage in rehabilitation (in those who able to be extubated (8)) and iii) in patients with high clot burden and limited vascular access due to IVC filter (Case 1), only a single insertion point is required.

There are some limitations to percutaneous RVAD use. It requires trained operators and facilities for the cannulae insertion which include intensivists, interventional cardiologists, a fully staffed interventional radiology or cardiac catheterisation suite, and an experienced MCS retrieval team. Our group have developed a hub and spoke system within a large region, with experienced personnel offering many years' experience of MCS and mobile ECLS. The decision for percutaneous RVAD or V-A ECMO in all our patients was carefully considered with a multi-disciplinary team, particularly the decision for use of the newer single access dual-lumen RA to PA cannula, as this can be more time consuming than conventional dual site cannulation oxy-RVAD. The ProtekDuo can provide 4-5L/min blood flow. Should high flow MCS (more than 5L/min) be required, this cannula may not be sufficient, and a conventional two cannula approach should be considered, or the addition of a second venous drainage cannula, and return of oxygenated blood to both limbs of the dual-lumen cannula (11). Conversely, if low flow (<3L/min) is used the risk of thrombosis increases, particularly with an oxygenator incorporated into the circuit, and therefore would

require higher anticoagulation targets, which reduces the positive impact of a less invasive technique. This, with the added increased risk of intracerebral haemorrhage as shown in other double lumen cannulae (12) would limit the use of low blood flow with this cannula. Moreover, in our cases the RV was failing, and lower flows would not have provided adequate support. The decision for which form of MCS is offered is challenging and will depend on many factors; we have proposed an algorithm for RV MCS adapted from Kapur and colleagues (13) (Figure 4).

Most case studies mentioned in the literature were prior to the wider usage of the ProtekDuo dual lumen cannula, which was first approved by the U.S. Food and Drug Administration in 2016. Our case series although small, gives valuable evidence for its use. With increased experience of this and other single access dual-lumen cannulae, these may be the cannulae of choice for patients with isolated RV failure requiring RVAD support, particularly where vascular access is a problem, and the option of adding an oxygenator is required. More studies comparing the use of these single access, dual-lumen cannulae to other forms of RVAD, and other indications for MCS will be useful to further demonstrate safety and efficacy. There is increasing need for less invasive cannulation techniques (single entry vs dual entry cannulation) to enable more percutaneous forms of MCS as the need for ECLS increases.

## **Conclusion**

In patients with PE and isolated RV failure, refractory to standard therapies, percutaneous oxy-RVAD with a single access dual-lumen RA to PA cannula or conventional two cannulae oxy-RVAD is a feasible technique in providing support that allows right heart recovery and systemic oxygenation.

## REFERENCES

1. Belohlavek J, Dytrych V, Linhart A. Pulmonary embolism, part I: Epidemiology, risk factors and risk stratification, pathophysiology, clinical presentation, diagnosis and nonthrombotic pulmonary embolism. *Exp Clin Cardiol.* 2013;18(2):129-38.
2. Konstantinides SV, Meyer G, Becattini C, Bueno H, Geersing GJ, Harjola VP, et al. 2019 ESC Guidelines for the diagnosis and management of acute pulmonary embolism developed in collaboration with the European Respiratory Society (ERS). *Eur Heart J.* 2020;41(4):543-603.
3. Bhalla A, Attaran R. Mechanical Circulatory Support to Treat Pulmonary Embolism: Venoarterial Extracorporeal Membrane Oxygenation and Right Ventricular Assist Devices. *Tex Heart Inst J.* 2020;47(3):202-6.
4. Maybauer MO, Koerner MM, Swol J, Banayosy AE, Maybauer DM. The novel ProtekDuo ventricular assist device: Configurations, technical aspects, and present evidence. *Perfusion.* 2022;2676591221090607.
5. Ravichandran AK, Baran DA, Stelling K, Cowger JA, Salerno CT. Outcomes with the Tandem Protek Duo Dual-Lumen Percutaneous Right Ventricular Assist Device. *ASAIO J.* 2018;64(4):570-2.
6. Kremer J, Farag M, Brcic A, Zubarevich A, Schamroth J, Kreusser MM, et al. Temporary right ventricular circulatory support following right ventricular infarction: results of a groin-free approach. *ESC Heart Fail.* 2020;7(5):2853-61.
7. Badu B, Cain MT, Durham LA, 3rd, Joyce LD, Sundararajan S, Gaglianella N, et al. A Dual-Lumen Percutaneous Cannula for Managing Refractory Right Ventricular Failure. *ASAIO J.* 2020;66(8):915-21.
8. Mustafa AK, Joshi DJ, Alexander PJ, Tabachnick DR, Cross CA, Jweied EE, et al. Comparative Propensity Matched Outcomes in Severe COVID-19 Respiratory Failure-Extracorporeal Membrane Oxygenation or Maximum Ventilation Alone. *Ann Surg.* 2021;274(5):e388-e94.
9. Geller BJ, Morrow DA, Sobieszczyk P. Percutaneous right ventricular assist device for massive pulmonary embolism. *Circ Cardiovasc Interv.* 2012;5(6):e74-5.
10. Lo Coco V, Swol J, De Piero ME, Massimi G, Chiarini G, Broman LM, et al. Dynamic extracorporeal life support: A novel management modality in temporary cardio-circulatory assistance. *Artif Organs.* 2021;45(4):427-34.
11. Maybauer MO, Koerner MM, Mihu MR, Harper MD, El Banayosy A. The ProtekDuo as double lumen return cannula in V-VP ECMO configuration: A first-in-man method description. *Ann Card Anaesth.* 2022;25(2):217-9.
12. Mazzeffi M, Kon Z, Menaker J, Johnson DM, Parise O, Gelsomino S, et al. Large Dual-Lumen Extracorporeal Membrane Oxygenation Cannulas Are Associated with More Intracranial Hemorrhage. *ASAIO J.* 2019;65(7):674-7.
13. Kapur NK, Esposito ML, Bader Y, Morine KJ, Kiernan MS, Pham DT, et al. Mechanical Circulatory Support Devices for Acute Right Ventricular Failure. *Circulation.* 2017;136(3):314-26.

**Table 1. Summary of the 4 cases.**

|               | <b>Age, Sex</b> | <b>Pathology</b>                                                                          | <b>Cannula Type and cannulation site</b> | <b>Cannulation guidance</b>            | <b>Cannulation location</b>         | <b>Pump and oxygenator</b>                     | <b>Highest Blood flow required</b> | <b>Days requiring RVAD</b> | <b>Complications</b>                              | <b>Outcome</b>                                                                                                                |
|---------------|-----------------|-------------------------------------------------------------------------------------------|------------------------------------------|----------------------------------------|-------------------------------------|------------------------------------------------|------------------------------------|----------------------------|---------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------|
| <b>Case 1</b> | 30M             | Hepatic adenoma. Bilateral PE Thrombus in IVC and Iliac vein. Previous surgical admission | ProtekDuo 29Fr RIJV                      | Fluoroscopic and transoesophageal echo | Intervention suite Referring centre | Cardiohelp Integrated Maquet HLS advanced 7.0L | 3.1L/min                           | 10                         | None                                              | RV returned to normal size and function. Normal PAP Discharged from local hospital                                            |
| <b>Case 2</b> | 22F             | ? Ectopic pregnancy, OOHCA 50mins total. Bilateral PE No previous hospital admission      | ProtekDuo 29Fr RIJV                      | Fluoroscopic                           | Intervention Suite Referring centre | Centrimag Medos Hilite 7L                      | 4.5L/min                           | 5                          | Bleeding from cannulation sites and epistaxis     | RV returned to normal size and function. Hypoxic brain injury. Died on day 9.                                                 |
| <b>Case 3</b> | 63 M            | H1N1 Influenza and MSSA bacteraemia. In-hospital cardiac arrest 8 mins. Left segmental PE | ProtekDuo 29Fr RIJV                      | Fluoroscopic                           | Intervention suite Referring centre | Cardiohelp Integrated Maquet HLS advanced 7.0L | 3.2L/min                           | 5                          | GI bleeding requiring gastric artery embolisation | RV returned to normal size and function. Repatriated to local hospital. Died 2 weeks later from Multi-organ failure from ARDS |

|               |     |                                                                                                               |                                                                                                                     |              |                                       |                              |          |    |                    |                                                                       |
|---------------|-----|---------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|--------------|---------------------------------------|------------------------------|----------|----|--------------------|-----------------------------------------------------------------------|
| <b>Case 4</b> | 45F | IVF and OHS<br>Ectopic pregnancy.<br>Recent surgical admission.<br>OOH Cardiac arrest 20 mins<br>Bilateral PE | Biomedicus<br>Multi-stage 25Fr<br>drainage in right femoral vein<br>Biomedicus 23Fr single-stage return in left IJV | Fluoroscopic | Intervention suite<br>Tertiary centre | Centrimag<br>Medos Hilite 7L | 4.4L/min | 10 | GI and GU bleeding | RV returned to normal size and function.<br>Discharged from hospital. |
|---------------|-----|---------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|--------------|---------------------------------------|------------------------------|----------|----|--------------------|-----------------------------------------------------------------------|

**Table 1. Summary of the 4 cases.** All patients received heparin infusion to maintain anti-Xa target of 0.2-0.3U/ml.

PE, pulmonary embolus; IVC, inferior vena cava; RV, right ventricle; PAP, pulmonary artery pressure; OOHCA, out of hospital cardiac arrest; MSSA, methicillin sensitive staphylococcus aureus; IVF, in-vitro fertilisation; ARDS, acute respiratory distress syndrome; OHS, ovarian hyperstimulation syndrome; RIJV, right internal jugular vein; RV, right ventricle; LIJV, left internal jugular vein; GI, gastrointestinal; GU, genitourinary.

**Figure legends:**

**Figure 1. Fluoroscopy images during single access dual-lumen right atrium to pulmonary artery cannula insertion.**

A- Single access dual-lumen cannula with guidewire in-situ

B –Contrast given to the return lumen of single access dual-lumen cannula in the pulmonary artery.

**Figure 2. Chest radiographs of RVAD devices in situ.**

2A - Case 1: single access dual-lumen cannula for PE.

2B - Case 2: single access dual-lumen cannula for PE.

2C. Case 3: single access dual-lumen cannula for PE and H1N1 ARDS

2D. Case 4: Two cannulae RVAD - right femoral drainage cannula, left IJV return cannula with tip in right PA.

**Figure 3. Illustrations of cannulae configuration and position within the right heart for oxy-RVAD**

3A – Configuration for single access dual-lumen cannula for Oxy-RVAD using a Cardiohelp and integrated Maquet HLS Oxygenator.

3B – Configuration for percutaneous 2 cannulae RVAD with drainage via the right femoral vein and return cannula inserted via the RIJV, with tip in the PA. Connected to a Cardiohelp and integrated Maquet HLS Oxygenator.

**Figure 4. Proposed algorithm for right ventricular mechanical circulatory support for used in RV failure due to pulmonary embolism. PE, pulmonary embolism; SBP; systolic blood pressure; RV, right ventricle; ECPR, extracorporeal**

cardiopulmonary resuscitation; LV, left ventricle; V-A-ECMO venoarterial extracorporeal membrane oxygenation; RVAD, right ventricular assist device.

Adapted from Kapur et al. (2017) [11]