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Extracorporeal CPR for massive pulmonary embolism in a "hybrid emergency department"

Kazuki Miyazaki *, Mayu Hikone, Yusuke Kuwahara, Takuto Ishida, Kazuhiro Sugiyama, Yuichi Hamabe

Trauma and Critical Care Center, Tokyo Metropolitan Bokutoh Hospital, Tokyo, Japan

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ABSTRACT

Aim: Patients with massive pulmonary embolism (PE) have poor outcomes and their management remains challenging. An interventional radiology (IVR)-computed tomography (CT) system available in our emergency room (ER) allows immediate access to CT and extracorporeal membrane oxygenation (ECMO) with safe cannulation under fluoroscopy. We aimed to determine if initial treatment in this "hybrid ER" is helpful in patients with PE requiring extracorporeal cardiopulmonary resuscitation (ECPR).
Methods: The records of patients transferred to our hybrid ER between September 2014 and December 2017 who required ECPR for PE were reviewed.
Results: Nine consecutive patients (median age 50 [range 30–76] years) with PE requiring ECPR were identified in our hybrid ER. Five (55.6%) had at least one risk factor for PE. Six (66.7%) experienced an out-of-hospital cardiac arrest and 3 (33.3%) had a cardiac arrest in the hybrid ER. Right ventricular overload was detected on electrocardiography and bedside transthoracic echocardiography in all cases. The median pH, lactate, $PaCO_2$, and HCO_3 values on arterial blood gas analysis in the hybrid ER were 7.01 (6.68–7.26), 14 (8–22) mmol l^{-1}, 44.7 (23.8–60.5) mmHg, and 10.4 (6.7–14.1), respectively. Four patients (44.4%) received monteplase for thrombolysis. No patient underwent surgical embolectomy. The median duration of ECMO was 69 (38–126) h. There were two ECMO-related bleeding complications. Eight patients (88.9%) survived and one died of post-resuscitation encephalopathy after weaning from ECMO.
Conclusion: A hybrid ER may be useful for initial management of massive PE requiring ECPR and may help to improve outcomes.

1. Introduction

Patients with massive pulmonary embolism (PE) and hemodynamic instability have poor outcomes and their management remains challenging. The mortality rate is up to 50%–60% in these patients [1,2] and increases to 60%–65% when cardiopulmonary resuscitation (CPR) is required [3,4].

There is a direct association between severe right ventricular failure caused by acute ventricular overload and mortality, so prompt removal of thrombus is necessary [5]. Interventions such as surgical embolectomy, thrombolytic therapy, and catheter-directed treatment are indicated in patients with hemodynamically unstable PE. There have been reports of successful use of veno-arterial extracorporeal membrane oxygenation (VA-ECMO) during surgical or catheter embolectomy as well as for CPR during initial management [6-8]. The clinical benefits of VA-ECMO for massive PE have been reported [5,9,10]. Safe and prompt initiation of VA-ECMO is crucial for massive PE requiring extracorporeal cardiopulmonary resuscitation (ECPR).

The advent of interventional radiology-computed tomography (IVR-CT) has had a considerable impact on management of trauma patients, enabling simultaneous diagnosis and intervention without the need to relocate the patient. The term "hybrid emergency room" (hybrid ER) was coined by Kinoshita et al. to describe an ER equipped with IVR-CT [11]. Use of a hybrid ER reportedly decreases mortality in patients with severe trauma by shortening the delay until whole-body CT imaging and allowing early initiation of definitive treatment [11,12]. We believe that a hybrid ER allows safer and more rapid cannulation and initiation of ECMO, which may be effective for PE requiring ECPR. However, there

Abbreviations: CPR, cardiopulmonary resuscitation; ECG, electrocardiogram; ECMO, extracorporeal membrane oxygenation; ECPR, extracorporeal cardiopulmonary resuscitation; IABP, intra-aortic balloon pump; ICU, intensive care unit; IVR-CT, interventional radiology-computed tomography; OHCA, out-of-hospital cardiac arrest; PE, pulmonary embolism; TTE, transthoracic echocardiography; VA-ECMO, veno-arterial extracorporeal membrane oxygenation.

* Corresponding author.
E-mail address: miyazaki2nd@gmail.com (K. Miyazaki).

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has been no report validating the initial treatment of medical emergencies in a hybrid ER.

We launched a hybrid ER in July 2014, which has been widely used since for both trauma and medical emergencies. The objective of this study was to assess the effectiveness of VA-ECMO for cardiac arrest due to PE in a hybrid ER.

2. Materials and methods

2.1. Study design and setting

This retrospective descriptive study was performed at Tokyo Metropolitan Bokutoh Hospital, a tertiary emergency medical center located in an urban setting in the eastern part of Tokyo, Japan. Patients are only brought to our institution if they are judged to be in a critical condition by emergency medical services. In 2017, we admitted 1518 medical patients and 457 trauma patients.

We reviewed the medical records of patients with PE who were identified from the database in our intensive care unit and collected their clinical features and all relevant data. The study was approved by the institutional review board of Tokyo Metropolitan Bokutoh Hospital.

A hybrid ER was installed at our emergency center in July 2014 and is equipped with a multi-slice IVR-CT system (Aquilion CX, TSX-101A; Toshiba Medical System Corp., Tochigi, Japan). Our hybrid ER has a carbon-fiber fluoroscopic table with a movable C-arm combined with a sliding gantry CT scanner (Fig. 1). This equipment enables us to perform diagnostic and therapeutic procedures simultaneously in a single dedicated space. At our institution, all patients with multiple trauma are taken to the hybrid ER when available. Medical patients with vital signs indicating shock, requiring ECPR, or with sudden alteration of consciousness are also taken to a hybrid ER.

2.2. Patients

Patients who were transferred to the hybrid ER at Tokyo Metropolitan Bokutoh Hospital between September 2014 and December 2017 and required ECPR for PE were included in the study. The diagnosis of PE was confirmed by contrast CT scan and ECPR was performed in the hybrid ER. Patients were excluded if ECPR was not required or if a cardiac arrest occurred after transfer to an intensive care unit (ICU) because ECPR was performed in the ICU rather than in the hybrid ER.

2.3. VA-ECMO system

All ECMO cannulations were performed percutaneously. The cannulas were inserted in the femoral vessels under ultrasonographic and fluoroscopic guidance. The femoral vessels were punctured under guidance by a linear-type ultrasonic probe, followed by insertion of guide wires and dilators under fluoroscopic guidance. We used 16-F cannulas for the femoral artery and 22-F cannulas for the femoral vein. An additional 4-F catheter was inserted into the superficial femoral artery to prevent limb ischemia. The final positions of the cannulas and catheters were confirmed by fluoroscopy. The ECMO circuit consists of a centrifugal pump (HCF-MP23H) and a hollow-fiber HPO-23WH-C oxygenator (MERA CPB Circuit; Senko Medical Instrument Mfg. Corp., Tokyo, Japan).

2.4. Data collection

The data collected for analysis included demographics (age, sex, body mass index), risk factors for thromboembolism, timing of cardiopulmonary arrest (CPA), results of arterial blood gas analysis, electrocardiography, and transthoracic echocardiography, survival until hospital discharge, cerebral performance category, ECMO-related complications, overall duration of ECMO, length of stay in the intensive care unit, and duration of hospital stay.

3. Results

Twenty-five patients with PE were identified during our study period. Sixteen patients were excluded (14 without cardiopulmonary arrest, 1 in whom ECPR was not indicated because of hemoptysis, and 1 who suffered a cardiac arrest after admission to the ICU). The remaining 9 patients who had massive PE and underwent ECPR in the hybrid ER were included in our analysis (Fig. 2). The baseline characteristics of these 9 patients (5 women, 4 men; median age 50 [range 30–76] years) are shown in Table 1. Five (55.6%) patients had at least one risk factor for PE. Six (66.7%) had had an out-of-hospital cardiac arrest (OHCA) and 3 (33.3%) had a cardiac arrest in the hybrid ER. All patients had findings consistent with right ventricular overload on electrocardiography and bedside transthoracic echocardiography. Electrocardiography was conducted after ECPR in all patients and showed an organized rhythm with an S1Q3T3 pattern. Transthoracic echocardiography was performed during ECPR and showed right ventricular dilatation. Median pH, lactate, $PaCO_2$, and HCO_3 values on initial arterial

Fig. 1. Photograph showing our hybrid emergency room. (A) sliding gantry computer tomography scanner, (B) movable C-arm, (C) ultrasound equipment, (D) mechanical ventilator, (E) patient monitoring screen.

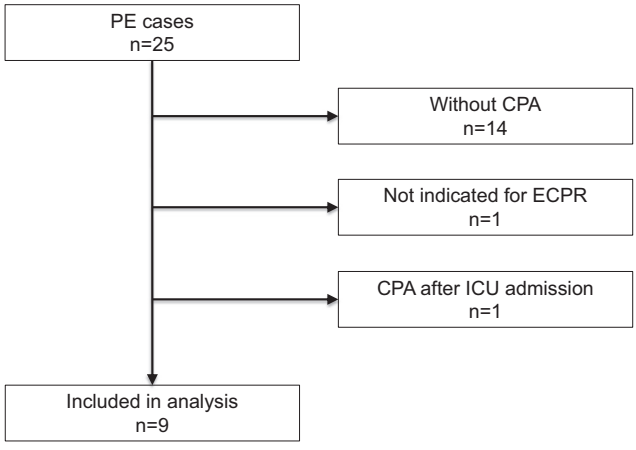

Fig. 2. Flowchart of study patients who underwent ECPR in the hybrid emergency room because of massive PE.PE, pulmonary embolism; CPA, cardiopulmonary arrest; ECPR, extracorporeal cardiopulmonary resuscitation.

Table 1
Patient demographic and clinical characteristics at the time of admission to the hybrid emergency room.

Case	Age (years)/Sex	BMI	Risk factors for VTE	OHCA	pH	$PaCO_2$ (mmHg)	Lactate (mmol/L)	HCO_3 (mmol/L)	S1Q3T3 on ECG	RV enlargement	Pre-ECMO condition
1	57/F	18.4	Immobility	No	7.258	32.8	7.5	14.1	Yes	Yes	Cardiac arrest
2	74/F	24.7	No	Yes	6.918	46.6	13.5	9	Yes	Yes	Cardiac arrest
3	32/M	25.3	Postoperative status	No	6.936	44.2	19	8.9	Yes	Yes	Cardiac arrest
4	43/M	–	No	Yes	7.011	48.9	12.9	11.8	Yes	Yes	Cardiac arrest
5	46/F	29.2	Immobility	Yes	7.024	44.7	12.1	11.1	Yes	Yes	Cardiac arrest
6	50/M	20.8	Previous DVT	Yes	6.676	60.5	22	6.7	Yes	Yes	Cardiac arrest
7	76/F	20.1	No	Yes	6.866	44.9	14.2	7.7	Yes	Yes	Cardiac arrest
8	53/M	21.2	Immobility	No	7.079	41.5	16	11.7	Yes	Yes	Cardiac arrest
9	30/F	25.4	No	Yes	7.262	23.8	11.4	10.4	Yes	Yes	Cardiac arrest

BMI, body mass index; DVT, deep vein thrombosis; ECG, electrocardiogram; ECMO, extracorporeal membrane oxygenation; OHCA, out-of-hospital cardiac arrest; RV, right ventricular; VTE, venous thromboembolism.

Table 2
Therapeutic interventions and clinical course.

Case	Thrombolytic treatment	Surgical embolectomy	Catheter – directed treatment	Duration of ECMO (hours)	ECMO-related complications	LV unloading devices	RRT	Stroke	ICU stay (days)	Hospital stay (days)	Outcome	CPC
1	Monteplase	No	No	75	None	No	No	No	10	40	Survival	1
2	No	No	No	61	Puncture site pseudoaneurysm	IABP	No	No	8	29	Survival	1
3	No	No	No	75	None	No	No	No	11	28	Survival	1
4	No	No	No	46	None	No	No	No	5	10	Dead	5
5	No	No	No	74	None	No	No	No	10	22	Survival	1
6	Monteplase	No	No	69	None	No	No	No	8	41	Survival	4
7	No	No	Yes	126	Puncture site hematoma	No	No	No	13	56	Survival	1
8	Monteplase	No	No	39	None	No	No	No	5	23	Survival	1
9	Monteplase	No	No	38	None	No	No	No	5	54	Survival	3

CPC, cerebral performance category; ECMO, extracorporeal membrane oxygenation; IABP, intra-aortic balloon pump; ICU, intensive care unit; LV, left ventricular; RRT, renal replacement therapy.

blood gas analysis in the hybrid ER were 7.01 (range 6.68–7.26), 14 (8–22) mmol l^{-1}, 44.7 (23.8–60.5) mmHg, and 10.4 (6.7–14.1), respectively.

Details of the treatment for PE and the clinical course in each patient are shown in Table 2. Four patients (44.4%) received monteplase as thrombolytic treatment; the other patients did not receive this agent because the emergency physicians considered the risk of bleeding would be too high. All patients received heparin as anticoagulant therapy. No patient underwent surgical embolectomy. One patient (case 7) received catheter-directed treatment on day 5 because of poor reduction of pulmonary artery pressure. One patient (case 2) received an intra-aortic balloon pump; no left ventricular unloading devices were used in the other patients because early recovery of hemodynamic stability was expected. The median duration of ECMO was 69 (38–126) h. There were two ECMO-related bleeding complications. Eight patients (88.9%) survived and one died of post-resuscitation encephalopathy after being weaned from ECMO. Two of the eight surviving patients had a cerebral performance category of 3 and 4 at the time of discharge from hospital.

4. Discussion

In this study, we investigated whether initial treatment in our hybrid ER was helpful for improving outcomes in adult patients with PE requiring ECPR. Patients transferred to our facility are selected by prehospital triage, so the patients with PE we encounter are either in a hemodynamically unstable state or in severe respiratory distress. Eleven of the 25 patients with PE who were transferred between July 2014 and December 2017 experienced a cardiac arrest, of whom 9 warranted ECPR in the hybrid ER. Our results indicate that the hybrid ER is indeed useful in the management of these patients and can help improve outcomes in this patient population.

The survival rate in patients with massive PE who have gone into cardiac arrest and then been treated with ECMO has been reported to be poor, varying from 30% to 70% [5,9,13,14], suggesting that the prognosis of massive PE requiring ECPR is not good. Although there have been reports on treatment strategies for massive PE, there have been none on the value and impact of hybrid ER or a similarly equipped facility.

In the present study, 8 (88.9%) of 9 patients survived to be discharged from hospital. Although the number of patients in our series is relatively small, our survival rate is higher than previously reported. Even the patient who died was able to be weaned from ECMO and survived to be discharged from the ICU.

VA-ECMO is considered to be the only effective way of reducing ventricular overload to allow rapid recovery of right ventricular function [10,13,15,16]. The survival rate is better in patients with massive PE who require ECMO than in patients who received ECMO for reasons unrelated to PE [3,9].

Hemodynamic compromise tends to occur early after admission in patients with massive PE [17]; these patients may experience sudden deterioration or cardiopulmonary arrest during their initial work-up or during transfer [13,18]. Generally, regardless of the primary disease, the survival rate is better when ECMO is initiated early after cardiac arrest [19]. The time needed to relocate the patient before therapeutic intervention is an impediment to rapid initiation of ECMO. A hybrid ER enables us to acquire CT images without needing to relocate the patient and to introduce ECMO with safe cannulation under fluoroscopy. For example, patient 1 went into cardiac arrest during the CT scan and ECMO was able to be introduced rapidly because the patient was in a hybrid ER.

Apart from patient 1, 6 of our patients had had an out-of-hospital cardiac arrest and 2 had a cardiac arrest soon after arrival in hospital; all had a pulseless electrical activity rhythm. In all cases, a diagnosis of massive PE was suspected from the finding of right ventricular overload on echocardiography, which led to the decision to use ECMO.

ECPR in a hybrid ER consists of conventional CPR with puncture guided by ultrasound followed by cannulation guided by fluoroscopy. Cannulation using both ultrasound and fluoroscopy has been reported to be safer than cannulation guided by ultrasound alone, and is associated with a lower incidence of complications [20]. Use of fluoroscopy may be advantageous in avoiding incorrect placement of cannulas and bleeding complications. Bleeding complications are a major problem when using ECMO [21] and are of significant concern in patients with massive PE requiring anticoagulation or thrombolytic therapy. There have been reports of complications, including major bleeds and incorrect placement of cannulas, in patients with massive PE who have received ECMO [10,13,22]. Although pseudoaneurysm (case 2) and hematoma (case 7) were noted at the cannulation site in our study, there were no serious complications affecting the clinical course or prognosis. Our findings indicate that cannulation guided by ultrasound and fluoroscopy is safer than the conventional cannulation method.

According to the guideline, the indications for VA-ECMO in the treatment of PE are limited [6]. Recommendations for patients with massive PE who are hemodynamically compromised or have gone into cardiac arrest are not well determined. According to our investigation, VA-ECMO is a reasonable therapy that allows sufficient time for additional treatments to be considered if needed. Therefore, when cannulation is performed safely, ECMO is a significant and effective treatment for patients with massive PE.

In trauma care, use of a hybrid ER contributes to a reduction in the time required for diagnosis and treatment and in the number of deaths from exsanguination [11]. A hybrid ER also enables a diagnosis to be made on contrast CT and for ECMO to be initiated simultaneously without needing to relocate the patient and ensures that the procedures are performed safely. However, a hybrid ER requires a large space and the cost of implementation is high. In September 2018, 11 hospitals in Japan had a hybrid ER compared with only two in September 2014.

There are several limitations to this study. The first is its retrospective single-center design. Second, the investigation was based on a case series targeting a relatively limited number of patients and no historical control group was included. Nevertheless, the results suggest that a hybrid ER may contribute to an improved survival rate in patients with massive PE.

5. Conclusions

Prompt and safe initiation of VA-ECMO is important for resuscitation in cases of massive PE requiring ECPR. Hybrid ERs, which do not require relocation of the patient, are a practical option for initial management and can contribute to better outcomes. However, there is limited information on hybrid ERs in the literature, so further research on their effectiveness is needed.

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Meeting presentation

None.

Declarations of interest

None.

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