Cohort Study

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Salvage pulmonary embolectomy following cardiac arrest: a 10-year experience

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Introduction: Acute pulmonary embolism (PE), particularly massive PE, presents significant mortality risk, often necessitating emergency intervention such as surgical embolectomy. The prognosis for patients undergoing such interventions, especially after cardiac arrest, remains poor due to hemodynamic complications. This study aims to evaluate the efficacy of salvage pulmonary embolectomy in patients experiencing cardiac arrest due to massive PE, focusing on survival outcomes and influential risk factors.
Methods: Conducted at a single center over 10 years, this retrospective study involved 21 patients who underwent surgical embolectomy post-cardiac arrest due to massive PE. Data were collected on patient demographics, clinical presentation, and outcomes, analyzing factors such as age, hospital stay, and operative details.
Results: Out of 21 patients, 13 survived 1 year post-operation, translating to a 1-year survival rate of 61.90%. Intra-hospital survival was 76.19% (16 patients). Notable findings included a significant association between increased age and higher mortality (hazard ratio = 1.14, $P = 0.024$), and a longer hospital stay post-procedure in non-survivors (hazard ratio = 1.52, $P = 0.03$).
Conclusion: Salvage pulmonary embolectomy can improve survival in patients with massive PE following cardiac arrest. However, outcomes heavily depend on the patient's age and the length of the hospital stay. Future studies should focus on refining surgical techniques and improving pre- and postoperative care to enhance survival rates further.

Keywords: cardiac arrest, cardiopulmonary resuscitation, embolectomy, pulmonary embolism

Introduction

Acute pulmonary embolism (PE) is the sudden obstruction of part of the pulmonary arterial vasculature, usually secondary to an embolization of a deep vein thrombosis within the lower limbs and pelvis[1]. Massive PE is an acute PE coupled with sustained hypotension (systolic blood pressure 40 mmHg for at least 15 min or requiring inotropic support), pulselessness, or persistent profound bradycardia (heart rate < 40 bpm with signs or symptoms of shock) according to The American Heart Association[2]. This form of PE has a 90-day mortality rate of 52%, which is considerably more than the 14% mortality rate of other forms of PE and is most likely the result of hemodynamic instability commonly seen in massive PE patients[3]. The mortality rate rises to 80% when massive PE patients undergoing embolectomy suffer cardiac arrest and require continuous cardiopulmonary resuscitation (CPR)[4], highlighting the need for a rapid response. Furthermore, patients who suffer cardiac arrest with non-shockable rhythms, especially asystole, have a significantly lower survival rate[5].

Cardiac arrest from PE typically occurs due to blockage within the pulmonary arteries, coupled with the release of substances that constrict blood vessels from the clots. This situation heightens the workload on the right ventricle (RV), causing it to fail and increase the pressure in the right atrium, eventually leading to cardiogenic shock. The excessive strain on the RV forces the ventricular septum to shift toward the left, reducing the filling and volume of the left ventricle (LV) during its relaxation phase. This sequence of events drastically lowers the preload of the LV, resulting in circulatory collapse[6].

Treatments for massive PE have evolved throughout the decades. In the past, surgical pulmonary embolectomy was reserved as a salvage procedure for patients who either failed or had an absolute contraindication to thrombolysis[7]. Still, the procedure has reemerged as an effective strategy for managing patients with massive PE[2]. The American College of Chest Physicians recommends surgical embolectomy in cases where death is likely before thrombolysis can take effect, as is the case for patients who are experiencing cardiac arrest due to PE[8]. A compelling study by Leacche *et al*. has concluded that an aggressive approach to large pulmonary emboli, including rapid diagnosis and prompt surgical intervention, has improved the results of surgical embolectomy.

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In their study, 47 patients underwent surgical embolectomy with an operative mortality rate of 6% and 3-year survival of 83%, yet significantly higher mortality rates were still observed in patients who underwent CPR[9].

Surgical embolectomy is recognized as a potent intervention for managing massive PE. However, the success of such surgery hinges critically on the precise timing of intervention and the expertise with which it is executed. In cases where massive PE leads to cardiac arrest, prognosis generally remains poor, often due to unsuccessful CPR resulting from the specific underlying conditions[10,11]. While extensive research has explored the outcomes of surgical embolectomy for massive PE, data on its effectiveness in cases resistant to CPR are still sparse. This report contributes to the existing knowledge by detailing our own experiences in conducting these procedures on patients with asystole due to massive PE at our institutions.

Materials and methods

Design and ethics

This study was designed as a retrospective cohort study and has been reviewed and approved by the Iran University of Medical Sciences ethics committee (IR.IUMS.FMD.REC.1402.172). This approval included a waiver of consent due to the retrospective nature of the study and the critical condition of the patients involved.

Patient selection and data collection

All patients experiencing asystole coupled with massive PE who were admitted to Rasool-E Akram and Firoozgar Hospitals from March 2012 to June 2022 were included in this retrospective cohort study.

The inclusion criteria consisted of: (1) the diagnosis of PE, initially based on bedside transthoracic echocardiography, with confirmation achieved by detecting a thrombus in the RV or pulmonary artery through transthoracic echocardiography, or, when feasible and available, via computed tomography angiography; (2) RV dilation (with an apical 4-chamber RV diameter divided by LV diameter > 0.9) or RV systolic dysfunction observed on transthoracic or transesophageal echocardiography (TEE); and (3) asystolic cardiac arrest confirmed by auscultation and electrocardiogram findings.

The exclusion criteria include: (1) pediatric population (age under 18 years); (2) patients with incomplete medical records or missing data necessary for analysis; (3) patients with contraindications to pulmonary embolectomy (e.g., severe coagulopathy, terminal illness); (4) patients who did not experience cardiac arrest as a result of PE; (5) patients who underwent pulmonary embolectomy with chronic pulmonary thromboembolism; and (6) Patients with concurrent severe comorbidities that may confound outcomes (e.g., end-stage renal disease and terminal cancer).

Relevant pre-, peri-, and postoperative data were collected from the electronic database of the hospital after the surgery. The patients were then followed for 1 year.

Description of surgical technique

The management approach followed established Advanced Cardiac Life Support guidelines, with a focus on prioritizing continuous and high-quality CPR. The resuscitation process began immediately with a compression rate of 100–120 compressions per minute, ensuring a depth of at least 5 cm. Full chest recoil was maintained between compressions to optimize circulation.

While CPR was ongoing, the airway was secured, and oxygen was administered through ventilation. If necessary, early intubation was performed to enhance oxygenation. The patient received a full-dose bolus of intravenous unfractionated heparin, typically at a dose of 500 units/kg, to prevent further clot propagation. Throughout this process, CPR was continued without interruption to ensure perfusion to vital organs, including the brain.

Concurrently, preparations were made for an emergency median longitudinal sternotomy, which provided direct access to the heart and great vessels. Once the thoracic cavity was opened, CPR transitioned from external chest compressions to open cardiac massage. This technique allowed the surgeon to manually compress the heart, improving perfusion efficacy.

During the surgical procedure, inotropic agents were administered to support blood pressure and enhance myocardial perfusion. These medications were delivered directly into the aortic root or through central venous access, optimizing coronary perfusion pressure to aid in myocardial recovery.

Following the sternotomy, the patient was prepared for bicaval cannulation, which involved inserting cannulas into the superior and inferior vena cava to initiate cardiopulmonary bypass (CPB). CPB temporarily replaced the heart and lungs' functions, maintaining systemic circulation and oxygenation during the surgical removal of the embolus. Throughout the procedure, the perfusionist monitored and adjusted arterial blood gases, electrolyte levels, and hemoglobin concentrations.

While on CPB, the surgical team made incisions in the pulmonary arteries, using retractors to expose the vessel walls. Careful extraction of the thrombus was performed using forceps and suction to avoid damaging the delicate structure of the pulmonary arteries. Complete removal of the embolus was prioritized to restore full patency to the arteries. If peripheral emboli were suspected, manual lung compression was performed to dislodge smaller clots from the peripheral vasculature. Suction was used to clear these emboli during the lung tissue compression (Fig. 1).

TEE was employed to evaluate the success of the thrombus removal, ensuring no residual emboli remained in the pulmonary arteries. Additionally, TEE assessed the restoration of right ventricular function post-thrombectomy.

After the embolus was successfully removed and cardiac function began to stabilize, the patient was gradually weaned from CPB. Inotropic support was continued as necessary to maintain adequate cardiac output. Hemodynamic parameters and TEE were used to confirm cardiac stability before discontinuing CPB.

Once the heart function was confirmed to be stable, the surgical team closed the chest. The sternotomy was closed in layers, ensuring proper hemostasis. Postoperatively, the patient was transferred to the intensive care unit for close monitoring. Continued anticoagulation therapy was initiated to prevent further thromboembolic events, with long-term management including warfarin or direct oral anticoagulants, depending on the individual clinical scenario.

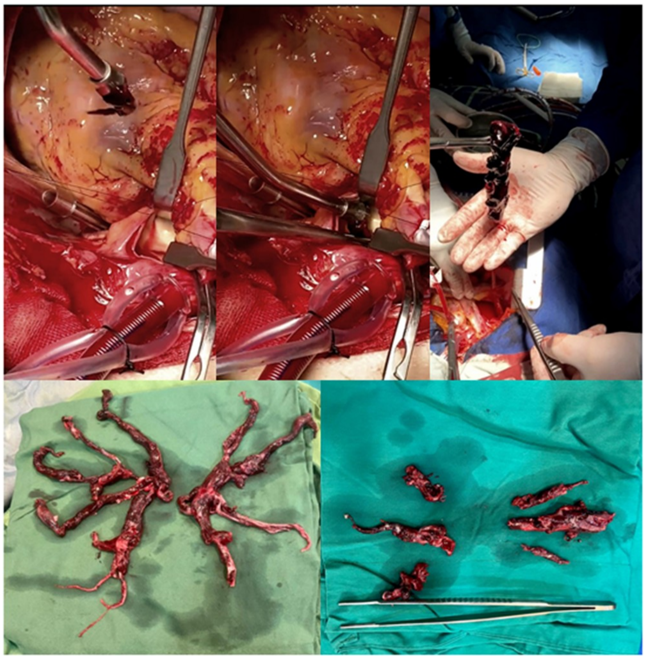

Figure 1. Pulmonary emboli removed through incision in pulmonary arteries incision (embolectomy).

Patients were monitored for clinical findings and survival over a 1-year period

Statistical analysis

All statistical analyses were conducted using Stata version 18 (StataCorp. 2023. Stata Statistical Software; College Station, TX, USA). The outcome for our analysis was defined as 1-year survival. Kaplan–Meier survival curves were generated to estimate the 1-year survival probability of patients undergoing salvage pulmonary embolectomy following cardiac arrest due to massive pulmonary thromboembolism. Survival time was defined as the time from the date of the procedure to either death or the end of the 1-year follow-up period, whichever occurred first. To evaluate the association between various factors and 1-year survival, a Cox proportional hazards model was employed. Hazard ratios (HRs) with 95% confidence intervals (CIs) were calculated to assess the strength and direction of these associations. A *P*-value < 0.05 was considered statistically significant. The proportional hazards assumption for the Cox model was assessed using Schoenfeld residuals. Non-proportional hazards were addressed by including time-dependent covariates or stratifying the analysis by the variable violating the assumption.

This study is reported according to the strengthening the reporting of cohort, cross-sectional, and case–control studies in surgery (STROCSS 2021)[12].

Results

Demographic and clinical findings

The study encompassed 21 patients who underwent salvage pulmonary embolectomy after in-hospital cardiac arrest triggered by massive pulmonary thromboembolism. The demographic breakdown revealed an average age of 60.76 years (SD = 9.08) with a majority of male patients (66.66%). Hypertension (42.85%) and diabetes (28.57%) were prevalent comorbidities. Prior surgical history was noted in 61.90% of the patients. The intervention was performed on average 69.14 h (SD = 38.68) after symptom onset, utilizing CPB for an average of 35.86 min (SD = 10.51). The average duration of hospital stay post-procedure was 9.25 days (SD = 3.09). Causes of death included right ventricular failure (37.5%), multi-organ failure (25%), persistent hypoxemia (25%), and sepsis (12.5%) (Table 1).

Survival results and mortality risk factors

Around 21 patients were evaluated over a 1-year period, during which 13 patients survived and eight passed away. Specifically, five patients died while hospitalized, resulting in an intra-hospital survival rate of 76.19%. Additionally, three patients died after being discharged, leading to a 1-year survival rate of 61.90% (Fig. 2).

The mean age of survivors was significantly lower (57.31 ± 6.46 years) compared to those who did not survive (66.38 ± 10.28 years), with an associated HR of 1.14 (95% CI: 1.01–1.27, *P* = 0.024). Gender distribution showed 69.23% of survivors were male, compared to 62.5% of those who did not survive, but this difference was not statistically significant [HR = 0.35 (0.083–1.5), *P* = 0.159; Table 2].

The prevalence of prior surgeries was similar between the groups [61.53% in survivors vs. 62.5% in non-survivors; HR = 0.95 (0.22–3.98), *P* = 0.946]. Conditions like the presence of tumors and trauma showed no significant differences in survival rates [HR = 0.82 (0.1–6.73), *P* = 0.859 and HR = 0.61 (0.12–3.07), *P* = 0.557, respectively; Table 2].

Medical comorbidities such as diabetes and hypertension were also not significantly different between the groups, with HRs of 1.55 (0.37–6.49, *P* = 0.547) and 1.39 (0.34–5.56, *P* = 0.641), respectively. Interestingly, the presence of syncope was associated with a higher hazard of death [HR = 3.69 (0.916–14.88), *P* = 0.066], though this did not reach statistical significance (Table 2).

Table 1

Demographic and clinical findings of the patients.

Variable	Mean/Count	Standard deviation/percent
Age (year)	60.76	9.08
Gender		
Male	14	66.66
Female	7	33.33
Prior surgery	13	61.90
Trauma	6	28.57
Tumor	3	14.28
Diabetes	6	28.57
Hypertension	9	42.85
Syncope	5	23.80
Time from symptoms onset (hour)	69.14	38.68
Cardiopulmonary bypass time (minute)	35.86	10.51
Time of discharge (day)	9.25	3.09
Cause of deaths		
Right ventricular failure	3	37.5
Multi-organ failure	2	25
Persistent Hypoxemia	2	25
Sepsis	1	12.5

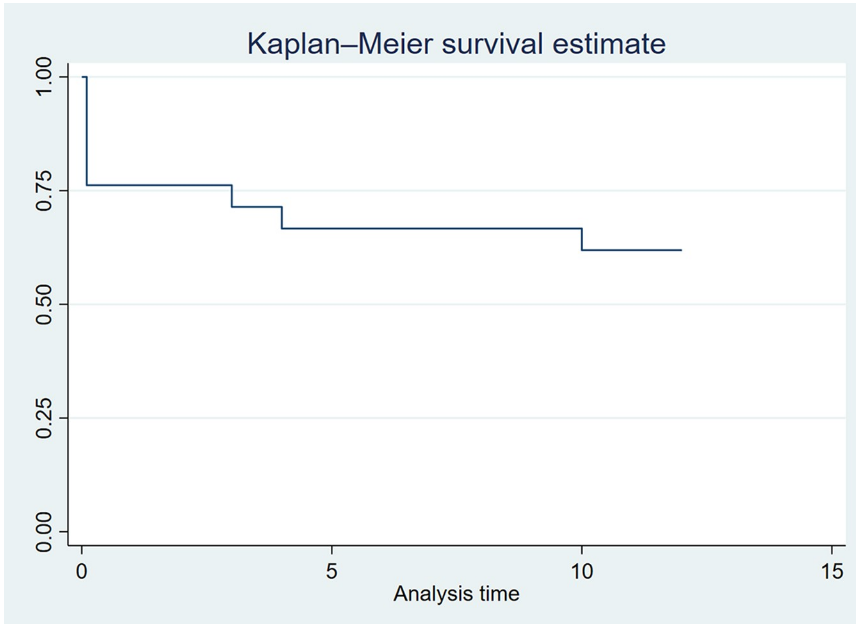

Figure 2. Kaplan–Meier 1-year survival graph of embolectomy patients.

The time from symptom onset to intervention did not significantly impact survival, with survivors experiencing an average of 70.15 ± 42.10 h and non-survivors 67.50 ± 35.10 h [HR = 0.99 (0.98–1.01), *P* = 0.932]. However, CPB time tended to be longer in non-survivors (41.38 ± 12.89 min) compared to survivors (32.46 ± 7.37 min), showing a trend toward significance [HR = 1.041 (0.99–1.09), *P* = 0.099].

The duration of hospital stay post-procedure was notably different, with non-survivors having a significantly longer stay (12.67 ± 4.73 days) compared to survivors (8.46 ± 2.15 days), with an HR of 1.52 (1.04–2.22, *P* = 0.03) (Table 2).

Discussion

Our study investigated the outcomes of salvage pulmonary embolectomy in patients who suffered cardiac arrest due to massive PE, a critical condition with historically high mortality rates. Despite advancements in medical interventions, the prognosis following cardiac arrest triggered by massive PE remains challenging, with significant variability in survival rates reported across various studies. Among the 21 patients assessed, the intra-hospital and 1-year survival rates stood at 76.19% and 61.90%, respectively. Notably, age emerged as a significant risk factor, with the mean age of survivors at 57.31 years compared to 66.38 years for those who did not survive, exhibiting an HR of 1.14 (95% CI: 1.01–1.27, *P* = 0.024). Additionally, the duration of hospital stay post-procedure significantly differed between survivors and non-survivors, with non-survivors tending to have a longer hospital stay, indicated by an HR of 1.52 (1.04–2.22, *P* = 0.03). These factors, among others explored in our analysis, highlight the complexities involved in managing this high-risk patient population and reinforce the importance of age and immediate postoperative recovery in influencing survival outcomes.

The results of our study compare favorably with the outcomes obtained by similar reports across the literature. Leacche *et al.*, who studied surgical embolectomy as an emergency treatment for massive PE, reported that in the 47 patients with massive PE,

Table 2

Risk factors for one-year mortality following salvage embolectomy.

Variable	1-year Survival (n = 13)	1-year Death (n = 8)	Hazard ratio [confidence interval]	*P*-value
Age. mean (SD)	57.31 (6.46)	66.38 (10.28)	1.14 [1.01–1.27]	0.024*
Male (%)	9 (69.23%)	5 (62.5%)	0.35 [0.083–1.5]	0.159
Prior surgery (%)	8 (61.53%)	5 (62.5%)	0.95 [0.22–3.98]	0.946
Tumor (%)	2 (15.38%)	1 (12.5%)	0.82 [0.1–6.73]	0.859
Trauma (%)	5 (38.46%)	1 (12.5%)	0.61 [0.12–3.07]	0.557
Diabetes (%)	3 (23.07%)	3 (37.5%)	1.55 [0.37–6.49]	0.547
Hypertension (%)	5 (38.46%)	4 (50%)	1.39 [0.34–5.56]	0.641
Syncope (%)	1 (7.7%)	3 (37.5%)	3.69 [0.916–14.88]	0.066
Hours since symptom onset. mean (SD)	70.15 (42.10)	67.50 (35.10)	0.99 [0.98–1.01]	0.932
Cardiopulmonary bypass time (SD)	32.46 (7.37)	41.38 (12.89)	1.041 [0.99–1.09]	0.099
Time of discharge (SD)	8.46 (2.15)	12.67 (4.73)	1.52 [1.04–2.22]	0.03*

*P-value < 0.05

six patients experienced pre-operative cardiac arrest, two of whom did not survive, culminating in a 33% mortality rate among the asystolic patients[9]. Ullman *et al.* reported that of the 19 patients who required CPR in the operating room, 12 did not survive, which resulted in a mortality rate of 63%[4]. Clarke and Abrams *et al.*, who described a 25-year experience of encountering patients with PE, reported that 84% of the patients who experienced asystole or ventricular fibrillation did not survive[11]. Takahashi *et al.* (2012) examined 24 patients who underwent surgical embolectomy for acute PE with circulatory collapse, reporting an in-hospital mortality rate of 12.5%. Notably, one patient required a second embolectomy due to complications, and the cumulative 5-year survival rate was 87.5%[13]. Fukuda *et al.* (2011) retrospectively reviewed 19 patients who underwent pulmonary embolectomy for massive PE. The operative mortality was 5.3%, and the 10-year survival rate was 83.5%[14]. Vohra *et al.* (2010) investigated the outcomes of 21 patients who underwent pulmonary embolectomy, with an in-hospital mortality rate of 19%. Postoperative complications included stroke, respiratory infections, and renal failure. At 5 and 8 years, actuarial survival rates were 76.9% and 51.2%, respectively. These studies demonstrate the effectiveness of surgical embolectomy for high-risk PE patients, though complications and mortality rates vary depending on the patient's condition and timing of intervention[15]. One of the key factors contributing to the differences between studies is the timing of the intervention. Patients who undergo surgical embolectomy prior to significant hemodynamic compromise typically experience better outcomes compared to those whose procedures are delayed until after cardiac arrest, as noted by Leacche *et al.* Another factor that may account for the variation in responses is the heterogeneity of patient characteristics and hospital settings, including differences in age, comorbidities, emergency services, hospital policies, and available equipment. These variables can have a more pronounced impact in studies with limited sample sizes, potentially influencing the observed outcomes.

Although we had a small sample size, we could identify higher age as a significant predictor of mortality. This is not surprising, as old age has long been identified as a predictor of poor outcomes in the literature. Van Hoeyweghen *et al.*'s analysis of 2776 patients suffering cardiac arrest concluded that mortality after CPR was significantly higher in elderly patients and had a negative effect on survival in resuscitated elderly patients[16]. Furthermore, Deasy *et al.*'s investigation of 30 006 patients undergoing CPR revealed that rates of attempted resuscitation decreased with advancing age: 48% for those aged 65–79 years, 39% for octogenarians, 31% for nonagenarians, and 17% for centenarians[17]. In addition, Pleskot *et al.* also found that of 560 patients suffering from cardiac arrest with a primary cardiac etiology, 2% of patients older than 70 years and 10% of patients younger than 70 survived 5 years, observing a trend of worse outcomes in those older than 70 years old[18].

The association between the length of hospital stay (LOS) and higher mortality rates in patients can be explained through several factors. One primary reason is that a longer LOS often indicates a more severe initial illness or the development of complications during the hospital stay. Patients with extended LOS are likely to have more complex health issues, which inherently carry a higher risk of mortality[19]. This is particularly evident in critical care units where longer stays might be associated with severe infections, multiple organ failure, or other life-threatening conditions[20]. Moreover, longer hospital stays can increase the risk of hospital-acquired infections and other iatrogenic conditions, which further complicate patient outcomes and can lead to higher mortality rates. Additionally, the longer patients remain in hospital settings, especially in intensive care units, the more resources they consume, which can strain the system and potentially impact the quality of care received[21].

The LOS is often used as a surrogate measure for the severity of illness and the intensity of the health care resources utilized. Thus, prolonged LOS not only reflects the critical nature of a patient's condition but also serves as an indicator of the health care system's burden, potentially leading to increased mortality rates due to stretched resources and management challenges[21].

The current study has several limitations that should be addressed in future research. First, the small sample size may limit the generalizability of the findings. Second, there is a need for more detailed and nuanced information regarding the preoperative and postoperative conditions of the patients. Third, it would be beneficial to consider the comorbidities and long-term complications of the patients during follow-up. Fourth, evaluating the use of new techniques such as extracorporeal membrane oxygenation in these patients could provide valuable insights.

This study is subject to several limitations, primarily due to its retrospective design. Retrospective cohort studies are inherently prone to biases such as missing data, unmeasured confounding factors, and dependence on existing records, which may have inconsistencies in documenting pre- and postoperative conditions, potentially leading to selection bias. Incomplete data on patient comorbidities and long-term follow-up also posed a challenge, and while we conducted sensitivity analyses to address this, some data gaps could still introduce bias. Additionally, over the 10-year study period, variations in surgical techniques and postoperative care protocols, driven by advancements in the field and surgeon preferences, may have influenced patient outcomes. Future prospective studies are encouraged to address these limitations by using standardized protocols and ensuring comprehensive data collection, which could enhance the accuracy of findings and offer a more robust assessment of long-term outcomes.

Conclusion

Overall, the surgical embolectomy technique we have outlined represents a promising method for treating patients with massive PEs who experience asystole. Notably, older age has emerged as a crucial risk factor for mortality, with older patients typically experiencing worse outcomes. Additionally, non-survivors tended to have a longer hospital stay post-procedure, highlighting the challenges of managing this high-risk patient group. These findings underline the importance of timely and precise surgical interventions in improving survival rates for patients with massive PE. Given these promising results, we recommend further research with more robust study designs to explore this approach in greater detail.

Ethics approval

This study has been reviewed and approved by the university ethics committee (IR.IUMS.FMD.REC.1402.172).

Consent

The ethics committee approval included a waiver of consent due to the retrospective design of the study and the critical condition of the patients involved.

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Author contribution

M.A.: Conceptualization, methodology, and investigation. I. M.: Conceptualization, methodology, and writing – review and editing. A.H.: Investigation. S.R.F.: Data curation and formal analysis. M.H.: Writing – original draft and investigation. B. H.: Writing – original draft and investigation. K.O.Y.: Writing – review and editing. S.Z.N.: Supervision and writing – review and editing. F.E.: Supervision and writing – review and editing.

Conflicts of interest disclosure

All the authors disclose the absence of any financial and personal relationships with other people or organizations that could inappropriately influence the work.

Research registration unique identifying number (UIN)

This study is registered with the Iran National Committee for Ethics in Biomedical Research through the Iran University of Medical Sciences. In accordance with the university regulations, all animal and human studies requiring ethical approval are registered in this registry.

1. Name of the registry: Iran National Committee for Ethics in Biomedical Research.
2. Unique Identifying number or registration ID: 26255.
3. Hyperlink to your specific registration (must be publicly accessible and will be checked): https://ethics.research.ac.ir/EthicsProposalViewEn.php?id=360101.

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Data availability statement

The supplementary data will be accessible upon request.

Provenance and peer review

This original article was not commissioned and has undergone formal peer review.

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