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Indigo Aspiration Thrombectomy Improves Right Heart Failure Caused by Acute Massive or High-Risk Submassive Pulmonary Embolism

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Abstract

Background: Acute pulmonary embolism (PE), particularly massive and high-risk submassive PE, carries mortality rates exceeding 50% and 15%, respectively. Anticoagulation alone does not effectively reduce mortality. Thrombolytic therapy improves outcomes but poses a substantial bleeding risk. Indigo aspiration thrombectomy alleviates right ventricular pressure overload in acute massive or high-risk submassive PE; however, its effect on PE-related mortality is unknown. This study aimed to determine whether Indigo aspiration thrombectomy improved right heart function and reduced PE-related mortality. **Methods**: This retrospective cohort study included 46 patients diagnosed with acute massive or high-risk submassive PE who underwent Indigo aspiration thrombectomy between January 2020 and August 2025. The study was conducted in the intensive care unit at China Medical University Hospital, Taichung, Taiwan. Efficacy endpoints were right heart parameters; safety endpoints included major bleeding events and 90-day mortality. Kaplan–Meier survival curve analysis was also performed. **Results**: Indigo aspiration thrombectomy significantly improved right heart parameters. Pulmonary artery (PA) systolic and mean pressures decreased by 23% (from 57.2 to 44.3 mmHg, $p = 0.001$; from 35.0 to 26.8 mmHg, $p < 0.001$). PA pulsatility index increased by 50%, and the right ventricular to left ventricular diameter ratio decreased by 30%. For acute massive PE, the major bleeding rate was 31.3% and PE-related mortality was 25.0%. For acute high-risk submassive PE, the major bleeding and PE-related mortality rates were both 3.3%. **Conclusions**: Indigo aspiration thrombectomy considerably improves right heart failure and may reduce PE-related mortality in patients with acute massive or high-risk submassive PE.

Keywords: acute pulmonary embolism; Indigo aspiration thrombectomy; right heart failure; pulmonary artery pressure; pulmonary artery pulsatility index

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1. Introduction

The incidence of acute pulmonary embolism (PE) is approximately 1/1000 [1]. Anticoagulants are the primary treatment for acute PE [2]. However, one-quarter of patients require emergent thrombolysis due to a high risk of death [3].

The European Society of Cardiology guidelines classify acute PE into four risk categories: high risk (massive), intermediate-high risk (high-risk submassive), intermediate-low risk (low-risk submassive), and low risk [4]. Acute massive PE signifies hemodynamic instability, such as a systolic blood pressure < 90 mmHg or obstructive shock. It accounts for approximately 5–10% of acute PE cases and carries a 90-day mortality rate of >50% with heparin alone [5]. Thrombolytic therapy (systemic or catheter-directed) is the primary treatment, and surgical thrombectomy may be used as an adjunct in cases of circulatory failure. Extracorporeal membrane oxygenation (ECMO) may be required for obstructive shock [6]. Acute submassive PE indicates increased right heart strain and mildly elevated troponin I levels. If the ratio of right ventricular (RV) to left ventricular (LV) diameter exceeds 1 [7], this condition is typically classified as acute high-risk submassive PE. Acute high-risk submassive PE comprises 10–20% of acute PE and carries a 90-day mortality rate of >15% with heparin alone. Thrombolytic therapy or surgical embolectomy is often performed in selected patients [8]. However, even with thrombolysis or embolectomy, acute massive or high-risk submassive PE still carries a high mortality rate [9].

The Penumbra Indigo® Aspiration System (Penumbra Inc., California, USA) is a large-bore aspiration thrombectomy device approved by the U.S. Food and Drug Administration for treating acute PE. Recent data indicate that, compared to thrombolytic therapy or surgical embolectomy, Indigo aspiration thrombectomy improves radiographic outcomes and has a lower incidence of major bleeding [10]. However, the survival benefit associated with Indigo aspiration thrombectomy remains unclear. This study aimed to determine whether Indigo aspiration thrombectomy improved right heart function and reduced PE-related mortality.

2. Materials and Methods

2.1 Study Design and Population

Data were retrieved from electronic hospital records, and written informed consent was waived due to the retrospective study design. The study protocol conformed to the ethical guidelines of the Institutional Review Board of China Medical University Hospital (CMUH114-REC3-201).

This observational, retrospective cohort study included 179 adult patients with acute massive or high-risk submassive PE who were consecutively admitted to the intensive care unit of China Medical University Hospital, Taichung, Taiwan, between January 2020 and August 2025. Patients who did not undergo Indigo aspiration thrombectomy were excluded from the study. A total of 46 patients were ultimately included in the statistical analysis (Strengthening the Reporting of Observational Studies in Epidemiology flowchart; Figure 1). Given the large proportion of patients with cancer, we excluded cases in which cancer was the cause of death to focus on Kaplan–Meier survival analysis on acute PE. For example, one patient was excluded from the acute massive PE group due to endometrial cancer with metastasis. Three patients were excluded from the acute high-risk submassive PE group because of duodenal cancer with metastasis, endometrial cancer with metastasis, and ruptured hepatocellular carcinoma.

2.2 Vital Signs (Blood Pressure, Heart Rate, Shock index, Respiratory Rate, Partial Pressure of Arterial Oxygen [PaO2]/Fraction of Inspired Oxygen [FiO2] ratio)

Vital signs included blood pressure, heart rate, and respiratory rate. The shock index was calculated as the ratio of heart rate to blood pressure; values > 1 indicate clinical shock. The PaO_2/FiO_2 ratio was used to assess oxygenation. A PaO_2/FiO_2 ratio of 200–300 indicates mild desaturation, 100–200 indicates moderate desaturation, and <100 indicates severe desaturation.

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2.3 Right Heart Parameters (Pulmonary Artery [PA] Pressure, Right Atrial Pressure, PA Pulsatility Index, RV/LV Diameter Ratio)

A Swan–Ganz right heart catheter was used to measure PA pressure and right atrial pressure. The PA pulsatility index was calculated as the ratio of PA pulse pressure to right atrial pressure. A PA pulsatility index < 1.8 indicates right heart failure [11].

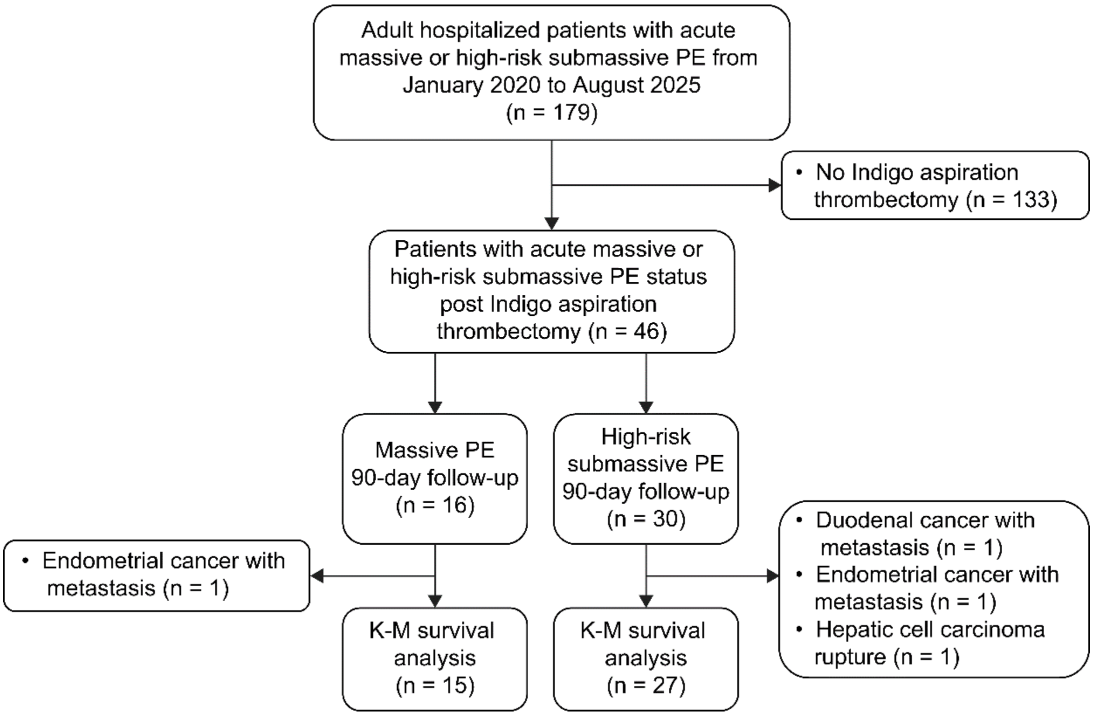

Figure 1. STROBE flow chart for patients with acute massive or high-risk submassive PE. A total of 179 adult patients with acute massive or high-risk submassive PE hospitalized between January 2020 and August 2025 were screened for evaluation. Patients who did not undergo Indigo thrombectomy were excluded from the study. A total of 46 patients were ultimately included in the statistical analysis. Given the large proportion of patients with cancer, cases in which cancer was the cause of death were excluded to focus on Kaplan–Meier survival analysis on acute PE. K-M, Kaplan–Meier; PE, pulmonary embolism; STROBE, Strengthening the Reporting of Observational Studies in Epidemiology.

2.4 Severity Evaluation (Percentage of Main Trunk or Bilateral, Mastora Obstruction Index, PE Severity Index)

If thrombi are distributed in the main PA or bilaterally, they are typically considered more severe. The Mastora occlusion index assesses the overall thrombus burden in the PA. A 1–5 scale is applied to each point based on the severity of occlusion: mediastinal artery occlusion, 5 points; lobar artery occlusion, 6 points; and segmental artery occlusion, 20 points. The maximum total score is 155. Scores > 85 indicate high risk, 55–85 indicate intermediate risk, and < 55 indicate low risk [12].

The PE severity index is a clinical tool that incorporates multiple factors, including age, sex, history of cancer or heart failure, heart rate, systolic blood pressure, respiratory rate, temperature, altered mental status, and oxygen saturation. A score > 140 (class V) indicates high risk, 110–140 (class IV–V) indicates intermediate-high risk, 80–110 (class III–IV) indicates intermediate-low risk, and < 80 (class I–II) indicates low risk [13].

2.5 Indigo Thrombectomy in Acute Massive or High-Risk Submassive PE

For acute massive or high-risk submassive PE, thrombolytic therapy is the preferred treatment. However, when patients have contraindications to thrombolysis (such as post-surgery, hemorrhagic stroke, recent ischemic stroke, malignant intracranial neoplasm, or active bleeding), clinicians may consider Indigo aspiration thrombectomy. A small proportion of patients undergo thrombectomy to establish a pathway for subsequent thrombolysis.

2.6 Statistical Analysis

The sample size was calculated to detect a clinically significant 67% reduction in the safety endpoint. Considering a 30% mortality rate in acute massive PE and 10% in acute high-risk submassive PE after thrombolysis, 177 patients (59 vs. 118) were required for 90% power at a two-sided alpha of 0.05, assuming 10% of cases would be non-evaluable. For research purposes, when the number of eligible patients with acute PE exceeded 177, only patients who underwent Indigo aspiration thrombectomy were included. Ultimately, 46 patients were analyzed.

Data are presented as mean ± standard deviation or as absolute numbers and percentages. Student's t-test was used to determine *p*-values, with $p < 0.05$ considered statistically significant. Kaplan–Meier 90-day survival curves were used to compare the acute massive and high-risk submassive PE groups. All analyses were performed using SPSS version 30.0 (IBM Corp., Armonk, NY, USA).

3. Results

3.1 Baseline Clinical Characteristics

Table 1 summarizes the baseline clinical characteristics of the study population, classified as acute massive or high-risk submassive PE. The mean age at diagnosis was 59 ± 16 years, and most patients were female (67.4%). Chronic conditions present in > 10% of patients included deep vein thrombosis (56.5%), hypertension (41.3%), cancer (34.8%), diabetes mellitus (21.7%), surgery (21.7%), immobility (19.6%), and hemorrhage stroke (10.9%). Notably, one-third of patients had cancer.

Regarding severity assessment, there was no significant difference in the proportion of lesions located in the main pulmonary artery or bilaterally. Although acute massive PE appeared to carry a greater thrombus burden than high-risk submassive PE, this difference was not statistically significant (87.0 vs. 78.4, $p = 0.05$). Since acute massive PE is defined by a systolic blood pressure <90 mmHg at admission, it showed a strong positive correlation with the PE severity index clinical score (161.6 vs. 127.1, $p = 0.003$).

Due to obstructive shock in acute massive PE, thrombolytic therapy using the EkoSonic intravascular system (EKOS) was applied at a relatively high rate, supplemented by ECMO support. In contrast, the proportion of EKOS thrombolysis in patients with high-risk submassive PE was lower, reflecting contradictions to thrombolytic therapy, such as post-surgery status, hemorrhagic stroke, or recent ischemic stroke.

Table 1. Baseline clinical characteristics of study participants by pulmonary embolism type (massive vs. high-risk submassive)

	All (n = 46)	**Massive PE (n = 16)**	**High-risk submassive PE (n = 30)**	***p*-value**
Age (y), mean ± SD	59 ± 16	61 ± 15	55 ± 19	0.21
Female sex, n (%)	31 (67.4)	12 (75.0)	19 (63.3)	0.43
Body mass index (kg/m²), mean ± SD	27.4 ± 6.3	26.5 ± 5.9	27.9 ± 6.5	0.50
Chronic disease				

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Pregnancy, n (%)	20 (4.3)	1 (6.3)	1 (3.3)	0.65
Smoking, n (%)	4 (8.7)	1 (6.3)	3 (10.0)	0.68
Surgery, n (%)	10 (21.7)	2 (12.5)	8 (26.7)	0.28
Immobility, n (%)	9 (19.6)	3 (18.8)	6 (20.0)	0.92
Atrial fibrillation, n (%)	2 (4.3)	0 (0.0)	2 (6.7)	0.30
Diabetes mellitus, n (%)	10 (21.7)	5 (31.3)	5 (16.7)	0.26
Hypertension, n (%)	19 (41.3)	9 (56.3)	10 (33.3)	0.14
Coronary artery disease, n (%)	2 (4.3)	0 (0.0)	2 (6.7)	0.30
Cancer, n (%)	16 (34.8)	3 (18.8)	13 (43.3)	0.10
Heart failure, n (%)	2 (4.3)	1 (6.3)	1 (3.3)	0.65
Hemorrhagic stroke, n (%)	5 (10.9)	1 (6.3)	4 (13.3)	0.47
Ischemic stroke, n (%)	3 (6.5)	1 (6.3)	2 (6.7)	0.96
Autoimmune disease, n (%)	3 (6.5)	2 (12.5)	1 (3.3)	0.24
Deep vein thrombosis, n (%)	26 (56.5)	7 (43.8)	19 (63.3)	0.21
Severity evaluation				
Main trunk or bilateral, n (%)	23 (50.0)	9 (56.3)	14 (46.7)	0.55
Mastora obstruction index, mean ± SD	81.4 ± 14.1	87.0 ± 12.0	78.4 ± 14.4	0.05
PE severity index at admission, mean ± SD	139.1 ± 39.2	161.6 ± 35.5	127.1 ± 36.1	0.003
Additional procedure				
Surgical embolectomy, n (%)	0 (0)	0 (0)	0 (0)	-
Systemic thrombolysis, n (%)	0 (0)	0 (0)	0 (0)	-
Catheter-directed thrombolysis, n (%)	21 (45.7)	10 (62.5)	9 (30.0)	0.03
EkoSonic endovascular system, n (%)	24 (52.2)	12 (75.0)	12 (40.0)	0.02
ECMO, n (%)	9 (19.6)	9 (56.3)	0 (0.0)	<0.001
Inferior vena cava filter, n (%)	37 (80.4)	11 (68.8)	26 (86.7)	0.15

ECMO, extracorporeal membrane oxygenation; PE, pulmonary embolism; SD, standard deviation.

3.2 Follow-Up of Laboratory Tests on the Day of Admission

The results of laboratory tests are presented in Table 2. Blood counts were measured on the day of admission. Patients with the massive subtype had higher initial white blood cell counts than those with the high-risk submassive subtype, indicating a more pronounced stress-related systemic inflammatory response in acute massive PE (13.6 vs. 9.9 K/μL, p = 0.02). Regarding coagulation factors, patients with acute massive PE exhibited lower fibrinogen levels but higher D-dimer levels, suggesting a higher thrombotic burden than those with acute high-risk submassive PE.

Among the biochemical indices, markers related to heart and kidney function were significantly elevated in the patients with massive PE, reflecting early organ injury. Although acute massive PE is associated with a higher systemic inflammatory response, initial high-sensitivity C-reactive protein levels were comparable to those in submassive PE due to its delayed response characteristics.

Table 2. Baseline blood counts and biochemical indices of study participants, depending on the presence of massive pulmonary embolism

	All (n = 46)	Massive PE (n = 16)	High-risk submassive PE (n = 30)	*p*-value
Blood counts				
WBC (K/μL), mean ± SD	11.2 ± 5.2	13.6 ± 4.9	9.9 ± 5.0	0.02
Hemoglobin (%), mean ± SD	11.4 ± 2.1	12.1 ± 2.1	11.0 ± 2.1	0.09
Platelet (K/μL), mean ± SD	232.2 ± 152.9	183.0 ± 95.8	258.4 ± 171.7	0.11
Coagulation factors				
Fibrinogen (mg/dL), mean ± SD	302.1 ± 123.5	238.6 ± 69.3	335.9 ± 133.2	0.009
D-dimer (ng/mL), mean ± SD	25315.1 ± 26166.4	37310.4 ± 29480.9	18917.6 ± 22162.1	0.02
Biochemical indices				
Troponin-I (ng/mL), mean ± SD	0.33 ± 0.60	0.65 ± 0.83	0.15 ± 0.31	0.005
Troponin-I > 0.04 ng/mL, n (%)	28 (60.9)	14 (87.5)	14 (46.7)	0.006
eGFR (mL/min), mean ± SD	80.5 ± 39.5	57.6 ± 26.4	93.6 ± 40.0	0.003
hsCRP (mg/dL), mean ± SD	4.7 ± 5.3	4.5 ± 4.8	4.8 ± 5.7	0.86

hsCRP, high-sensitivity C-reactive protein; eGFR, estimated glomerular filtration rate; PE, pulmonary embolism; SD, standard deviation; WBC, white blood cells.

3.3 Analyses of Indigo Thrombectomy Treatment Effect on Vital Signs and Right Heart Parameters

Table 3 summarizes the changes in vital signs and right heart parameters before and after thrombectomy. There were no statistically significant differences in blood pressure, heart rate, shock index, or respiratory rate before and after thrombectomy. However, the PaO_2 / FiO_2 ratio improved significantly after thrombectomy. Indigo aspiration thrombectomy significantly reduced PA systolic and mean pressures (from 57.2 to 44.3 mmHg, $p = 0.01$; from 35.0 to 26.8 mmHg, $p < 0.001$) and right atrial pressure (from 15.8 to 8.5 mmHg, $p < 0.001$). PA pulsatility index also increased markedly (from 2.2 to 3.3, $p < 0.001$). The RV/LV diameter ratio improved substantially, decreasing from 1.35 on pre-procedural computed tomography to 0.94 on follow-up echocardiography 48 h post-thrombectomy ($p < 0.001$). These improvements in right heart failure, including PA pressures, PA pulsatility index, and RV / LV ratio, are illustrated in Figure 2.

Table 3. Treatment effects of Indigo thrombectomy on study participants with pulmonary embolism

	Before thrombectomy (n = 46)	After thrombectomy (n = 46)	*p*-value
Vital signs			
Systolic blood pressure, mean ± SD	119.3 ± 23.1	125.7 ± 23.0	0.19
Mean artery pressure, mean ± SD	89.5 ± 16.7	92.4 ± 14.9	0.37
Diastolic blood pressure, mean ± SD	74.6 ± 15.5	75.8 ± 14.6	0.69
Heart rate, mean ± SD	100.8 ± 23.1	96.9 ± 21.1	0.40

Shock index, mean ± SD	0.88 ± 0.30	0.81 ± 0.29	0.22
Respiratory rate, mean ± SD	22.0 ± 5.7	20.0 ± 4.4	0.06
PaO2 / FiO2 ratio, mean ± SD	137.3 ± 57.6	270.6 ± 84.5	<0.001
Right heart parameters			
PA systolic pressure, mean ±SD	57.2 ± 18.8	44.3 ± 16.9	0.001
PA mean pressure, mean ± SD	35.0 ± 11.1	26.8 ± 10.1	<0.001
PA diastolic pressure, mean ± SD	23.9 ± 9.6	18.1 ± 8.7	0.003
Right atrial pressure, mean ± SD	15.8 ± 4.9	8.5 ± 3.2	<0.001
PA pulsatility index, mean ± SD	2.2 ± 1.1	3.3 ± 1.6	<0.001
RV / LV diameter ratio, mean ± SD	1.35 ± 0.25	0.94 ± 0.21	<0.001

FiO2, fraction of inspired oxygen; LV, left ventricular; PA, pulmonary artery; PaO2, partial pressure of arterial oxygen; RV, right ventricular; SD, standard deviation.

3.4 Clinical Outcomes after Indigo Thrombectomy

Table 4 presents the clinical outcomes following Indigo aspiration thrombectomy. Regarding vital signs, and consistent with the fundamental definition of massive APE, a significant proportion of patients with acute massive PE presented with elevated shock indices before thrombectomy. Concerning RV parameters, many patients with massive APE continued to show elevated PA pulsatility index and RV/LV diameter ratios after the procedure, indicating a limited response in terms of right heart failure improvement.

Patients with acute massive PE had a significantly higher incidence of major bleeding than those with acute submassive PE (31.3% vs. 3.3%, p = 0.007). No cases of intracranial hemorrhage or fatal bleeding occurred in either group.

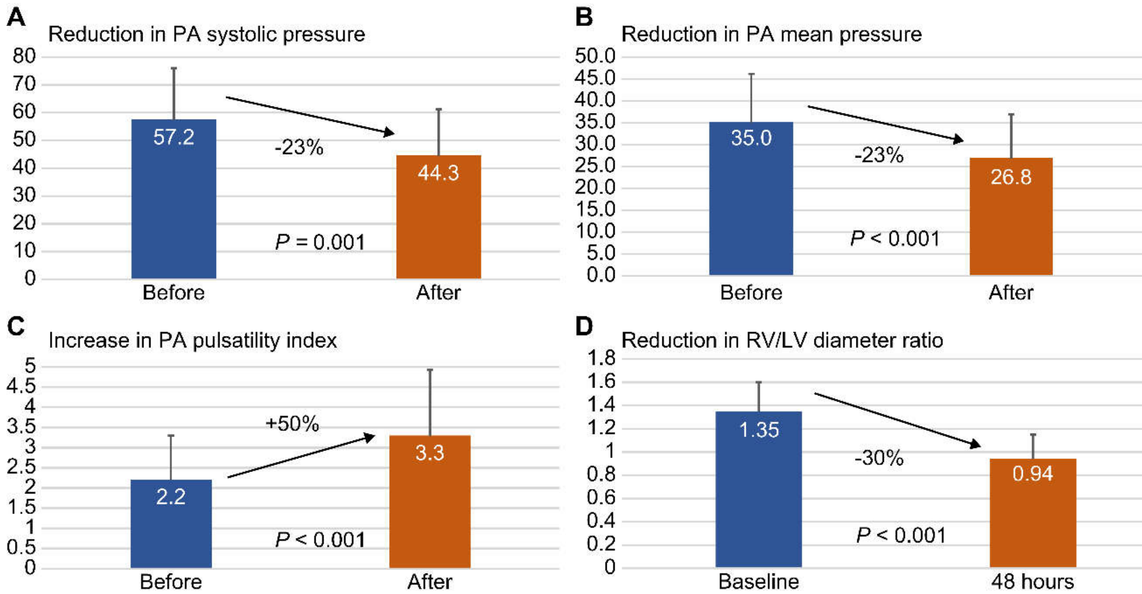

Figure 2. (A) Reduction in PA systolic pressure by 23% (from 57.2 to 44.3 mmHg, p = 0.001) before and after thrombectomy; (B) Reduction in PA mean pressure by 23% (from 35.0 to 26.8, p < 0.001) before and after thrombectomy; (C) Increase in PA pulsatility index by 50% (from 2.2 to 3.3, p < 0.001) before and after thrombectomy; (D) Reduction in RV/LV diameter ratio by 30% (from 1.35 to 0.94, p < 0.001) between baseline

and 48 h post-thrombectomy. **Abbreviations:** PA, pulmonary artery; RV, right ventricle; LV, left ventricle; RV/LV, right ventricular–to–left ventricular diameter ratio.

Due to the high proportion of patients with cancer, the difference in 90-day all-cause mortality between the two groups was not statistically significant. In the acute massive PE group, one death involving a patient with metastatic endometrial cancer was excluded. In the acute high-risk submassive PE group, three cancer-related deaths were excluded (metastatic duodenal cancer, metastatic endometrial cancer, and ruptured hepatocellular carcinoma). After excluding these cases, the 90-day PE-related mortality rate remained significantly higher in the acute massive PE group than in the high-risk submassive PE group (25.0% vs. 3.3%, $p = 0.02$).

Table 4. Clinical outcomes of study participants depending on the presence of massive pulmonary embolism

	All (n = 46)	**Massive PE (n = 16)**	**High-risk submassive PE (n = 30)**	***p*-value**
Vital signs				
Mean artery pressure before thrombectomy, mean ± SD	89.5 ± 16.7	80.6 ± 17.0	94.2 ± 14.7	0.007
Mean artery pressure after thrombectomy, mean ± SD	92.4 ± 14.9	89.5 ± 16.2	94.0 ± 14.2	0.33
Shock index before thrombectomy, mean ± SD	0.88 ± 0.30	1.11 ± 0.35	0.76 ± 0.18	<0.001
Shock index after thrombectomy, mean ± SD	0.81 ± 0.29	0.92 ± 0.40	0.75 ± 0.20	0.06
PaO2 / FiO2 ratio before thrombectomy, mean ± SD	137.3 ± 57.6	128.4 ± 59.1	142.1 ± 57.2	0.45
PaO2 / FiO2 ratio after thrombectomy, mean ± SD	270.6 ± 84.5	272.1 ± 97.4	269.8 ± 78.6	0.93
Right heart parameters				
PA mean pressure before thrombectomy, mean ± SD	35.0 ± 11.1	39.1 ± 12.1	32.8 ± 10.0	0.07
PA mean pressure after thrombectomy, mean ± SD	26.8 ± 10.1	28.3 ± 10.4	26.0 ± 10.1	0.47
PA pulsatility index before thrombectomy, mean ± SD	2.2 ± 1.1	2.0 ± 0.9	2.3 ± 1.2	0.30
PA pulsatility index after thrombectomy, mean ± SD	3.3 ± 1.6	3.7 ± 1.6	2.6 ± 1.2	0.02
RV / LV diameter ratio before thrombectomy, mean ± SD	1.35 ± 0.25	1.44 ± 0.2	1.29 ± 0.24	0.06
RV / LV diameter ratio after thrombectomy, mean ± SD	0.94 ± 0.21	1.05 ± 0.2	0.88 ± 0.19	0.01
Major bleeding				
BARC 3B bleeding, n (%)	6 (13.0)	5 (31.3)	1 (3.3)	0.007
BARC 3C bleeding, n (%)	0 (0.0)	0 (0.0)	0 (0.0)	-
BARC 5 bleeding, n (%)	0 (0.0)	0 (0.0)	0 (0.0)	-
Mortality				
90-day all-cause mortality, n (%)	9 (19.6)	5 (31.3)	4 (13.3)	0.15
90-day PE-related mortality, n (%)	5 (10.9)	4 (25.0)	1 (3.3)	0.02

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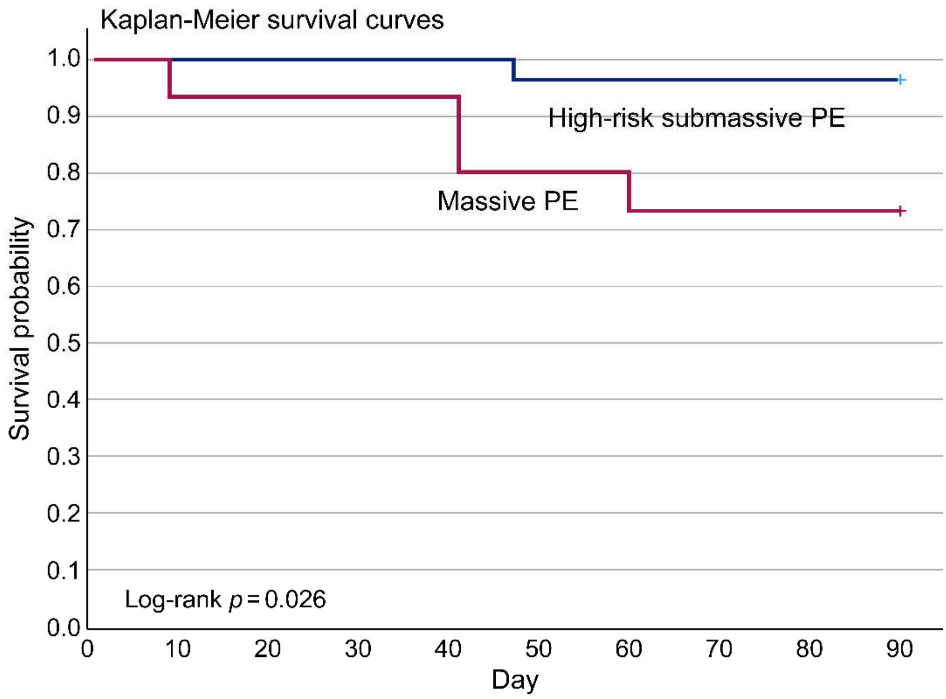
BARC, bleeding academic research consortium; FiO2, fraction of inspired oxygen; LV, left ventricular; PaO2, partial pressure of arterial oxygen; PA, pulmonary artery; PE, pulmonary embolism; RV, right ventricular; SD, standard deviation.

3.5 Ninety-day PE-related Survival Rate Analyzed by Kaplan–Meier Survival Curves

Figure 3 illustrates the Kaplan–Meier survival curves for patients with acute massive and acute high-risk submassive PE. The 90-day PE-related survival rate for patients with massive PE was 11/15 (73.3%), while that for patients with high-risk submassive PE was 26/27 (96.3%). Overall, patients with acute massive PE demonstrated significantly higher PE-related mortality than those with high-risk submassive PE (log-rank test $p = 0.026$).



Number at risk

	0	10	20	30	40	50	60	70	80	90
High-risk submassive PE	27	27	27	27	27	26	26	26	26	26
Massive PE	15	14	14	14	14	12	11	11	11	11

Figure 3. Kaplan–Meier 90-day PE-related survival in patients with acute massive and high-risk submassive PE. The 90-day survival rate was 11/15 (73.3%) for acute massive PE and 26/27 (96.3%) for high-risk submassive PE. Patients with acute massive PE had a significantly higher PE-related mortality than those with high-risk submassive PE (log-rank test $p = 0.026$). **Abbreviations**: PE, pulmonary embolism.

4. Discussion

In this study, we evaluated potential treatment options to improve PE-related mortality in patients with acute massive or high-risk submassive PE beyond basic anticoagulation therapy. Indigo thrombectomy has been applied to alleviate right heart failure and is typically used for more severe PE. In acute massive PE, Indigo thrombectomy is often employed as a pre-thrombolytic adjunct, while in acute high-risk submassive PE, it can serve as a direct alternative to thrombolysis in patients at high bleeding risk [14].

Indigo continuous aspiration thrombectomy produces immediate hemodynamic improvements, including reductions in PA systolic and mean pressures [15,16], followed by improvement in the PaO2/FiO2 ratio [17]. RV-PA uncoupling, defined as reduced tricuspid annular plane systolic excursion with elevated PA systolic pressure resulting in a tricuspid annular plane systolic excursion/PA systolic pressure ratio < 0.4 [18], is alleviated by Indigo thrombectomy, which rapidly reduces PA systolic pressure while maintaining normal tricuspid annular plane systolic excursion.

The PA pulsatility index, derived from the ratio of PA pulse pressure to right atrial pressure, reflects RV function [19]. By reducing right atrial pressure while maintaining PA pulse pressure, Indigo thrombectomy improves PA pulsatility index and mitigates the risk of right heart failure [20]. Following Indigo aspiration thrombectomy, both right atrial and ventricular pressures improve concurrently due to reductions in PA pressures. At 48-h follow-up, the RV/LV diameter ratio typically decreased by approximately 30% [21–23]; a ratio > 1 indicates high risk for right heart failure, while < 1 eliminates this risk [24].

In practice, catheter-directed thrombolysis has gradually replaced systemic thrombolysis to reduce the risk of cerebral hemorrhage, and percutaneous catheter aspiration thrombectomy has largely replaced surgical embolectomy to minimize vascular injury [25,26]. For acute massive PE, suction thrombectomy combined with thrombolysis is used to reduce bleeding and mortality, with ECMO (especially VA-ECMO) applied if obstructive shock occurs [27,28]. In this study, 56.3% of patients with acute massive PE received ECMO, including 50.0% VA-ECMO, 12.5% VAV-ECMO, and 12.5% VV-ECMO. Despite combined therapy, 90-day mortality decreased from >50% after heparinization alone to 15–45% after combined thrombolysis, with an average of 30% [29]. Acute high-risk submassive PE (such as RV/LV ratio >1) carries elevated mortality and often requires thrombolysis in addition to anticoagulation. Catheter-directed thrombolysis reduces 90-day mortality from >15% to 7–15% [30]. However, in certain situations, pharmaco-mechanical thrombectomy (such as Indigo aspiration thrombectomy) must be employed to reduce the risk of major hemorrhage associated with thrombolytic therapy. Contraindications to thrombolysis include post-surgery, hemorrhagic stroke, ischemic stroke within the preceding 6 months, malignant intracranial neoplasm, or active bleeding [31]. Patients with cancer face both hypercoagulability and bleeding risks due to an abnormally rich blood supply and tumor-related inflammation [32]. In this study, three patients had malignant hepatocellular carcinoma, three had endometrial cancer, two had lung cancer, two had tongue cancer, one had duodenal cancer, one had a malignant renal tumor, and one had a malignant intracranial neoplasm. Both patient groups exhibited elevated cardiac troponin I levels (> 0.04 ng/mL), indicating acute RV strain [33]. Overall, 87.5% of patients with acute massive PE and 46.7% patients with high-risk submassive PE had elevated troponin I levels.

In the acute massive PE group, the 90-day major bleeding rate was approximately 30%, and the 90-day PE-related mortality decreased from 30% to 25%. Subgroup analysis showed that combined Indigo thrombectomy and thrombolysis (10/16, 62.5%) had a PE-related mortality of 20.0%, whereas Indigo thrombectomy alone (6/16, 37.5%) had a PE-related mortality of 33.3%. These findings indicate that Indigo thrombectomy can further reduce mortality by 30% even when thrombolysis-related bleeding risk cannot be avoided. In the acute high-risk submassive PE group, the 90-day major bleeding rate decreased from 10% to 3%, and PE-related mortality decreased from 10% to 3%. Subgroup analysis showed that Indigo thrombectomy alone (21/30, 70%) had a PE-related mortality of 4.8%, while rescue thrombolysis following thrombectomy (9/30, 30%) had 0% mortality. These results indicate that Indigo thrombectomy not only reduces the risk of major bleeding but also lowers PE-related mortality when thrombolysis is contraindicated [34]. In summary, although thrombectomy and thrombolysis yield comparable all-cause mortality rates for acute massive and high-risk submassive PE, thrombectomy rapidly improves PA pressure and reduces right heart failure, resulting in superior PE-related survival [35].

This study has some limitations. First, despite achieving a sample size and statistical power of 90% for acute massive and high-risk submassive PE, Indigo aspiration thrombectomy still exhibits considerable selection bias, particularly among patients with cancer. Second, this study was conducted at a single center and may not be generalizable to other hospitals. Third, the influence of ECMO in massive PE remains unclear. Finally, prospective randomized studies are needed to verify these findings under specific circumstances.

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5. Conclusions

In this study, Indigo aspiration thrombectomy substantially improves right heart failure and may help reduce PE-related mortality in patients with acute massive or high-risk submassive PE. For acute massive PE, Indigo aspiration thrombectomy can enhance therapeutic efficacy when thrombolytic therapy is insufficient. For acute high-risk submassive PE, when contraindications such as post-surgery, hemorrhagic stroke, recent ischemic stroke, malignant intracranial neoplasm, or active bleeding exist, Indigo aspiration thrombectomy can replace thrombolytic therapy with comparable efficacy.

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Abbreviations

The following abbreviations are used in this manuscript:

ECMO	Extracorporeal membrane oxygenation
EKOS	EkoSonic endovascular system
FiO2	Fraction of inspired oxygen
LV	Left ventricular
PA	Pulmonary artery
PE	Pulmonary embolism
PaO2	Partial pressure of arterial oxygen
RV	Right ventricular

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