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Original Article

Balloon dilatation combined with thrombectomy reduces myocardial injury in massive pulmonary embolism

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Abstract: Objectives: To investigate the alterations in myocardial injury markers following balloon dilatation combined with thrombectomy in patients with massive pulmonary embolism (MPE). Methods: A retrospective study was conducted in 90 patients diagnosed with MPE. Clinical efficacy, Miller scores, pulmonary artery pressure (PAP), pulmonary artery diameter (PAD), and levels of myocardial injury markers were evaluated and compared between the combined treatment group (balloon dilatation plus thrombectomy) and the basic treatment group (basic therapy alone). Results: Compared to the basic treatment group, the combined treatment group exhibited significantly improved clinical efficacy, including higher rates of complete response, marked response, and overall response. Hemodynamic and cardiac function indices were significantly improved, as evidenced by lower post-treatment Miller score, PAP, PAD, and right ventricular/left ventricular (RV/LV) ratios. Myocardial injury and inflammation-related indicators, including myoglobin (MYO), troponin T (TnT), creatine kinase (CK), and fibrinogen (FIB) were significantly reduced at specific time points in the combined treatment group. Furthermore, significant correlations were identified between injury markers and arterial blood gas indices: CK at 24 hours was inversely correlated with arterial partial pressure of carbon dioxide ($PaCO_2$), and TnT at 72 hours was negatively associated with arterial partial pressure of oxygen (PaO_2). Conclusion: Balloon dilation combined with thrombectomy for the treatment of MPE can significantly reduce myocardial injury and inflammation-related indicators, thereby markedly improving clinical outcome.

Keywords: Balloon dilation, embolism, massive pulmonary embolism, reperfusion injury

Introduction

Massive pulmonary embolism (MPE) is triggered mostly by various embolic materials that occlude the main trunk or major branches of the pulmonary artery, thereby leading to severe clinical manifestations associated with pulmonary circulation disorders [1]. MPE is extremely dangerous and can result in death in a short time. Its major complications include acute right heart failure, respiratory dysfunction, and multiple organ dysfunction syndrome [2, 3].

At present, the main treatment methods for pulmonary embolism include anticoagulation, thrombolysis, and interventional therapy. Anticoagulation therapy is a basic treatment method that can prevent further thrombosis formation; thrombolytic therapy can quickly dissolve thrombi but is associated with a high risk of bleeding; interventional therapies (e.g., catheter thrombolysis, mechanical thrombectomy, balloon dilatation, and stent implantation) are particularly suitable for patients with acute MPE. Among these, balloon dilatation with thrombectomy therapy has emerged as an important interventional strategy. Balloon dilatation can restore pulmonary blood flow by dilating narrowed pulmonary arteries, while thrombectomy directly removes thrombotic material. Although these techniques have demonstrated certain application values in the treatment of MPE, they are also associated with potential complications, including ischemia-reperfusion injury and bleeding [4].

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Reperfusion injury refers to the paradoxical exacerbation of tissue damage following the restoration of blood flow to previously ischemic tissues [5]. After MPE treatment, reperfusion injury can lead to lung tissue damage, pulmonary edema, and respiratory dysfunction, significantly affecting the prognosis of patients [6]. Reperfusion injury is mediated by a series of bioactive substances produced during the reperfusion process, including reactive oxygen species (ROS), inflammatory mediators, and apoptosis factors. These factors contribute to cellular and tissue damage and aggravate the severity of reperfusion injury [7]. Investigating the dynamic changes in these factors explains the mechanisms underlying reperfusion injury and provides a theoretical basis for its prevention and management.

Therefore, this study aimed to investigate the changes in reperfusion injury-associated factors following balloon dilatation combined with thrombectomy in patients with MPE, with the goal of optimizing therapeutic strategies, reducing complication risk, and improving clinical outcomes.

Materials and methods

Research subjects

This study was conducted in accordance with the ethical principles of the Declaration of Helsinki and was approved by the Ethics Committee of Beiliu People's Hospital (approval number: AF/SW-03/03.1). This retrospective study included patients diagnosed with MPE who were admitted to Beiliu People's Hospital between July 2023 and June 2024.

Inclusion criteria: (1) Meeting the clinical diagnostic criteria for MPE [8]: ① Presence of shock or hypotension, defined as systolic blood pressure <90 mmHg or a decrease of ≥40 mmHg from baseline lasting for more than 15 minutes (excluding blood pressure drops caused by new-onset arrhythmia, hypovolemia, or sepsis); ② Pulmonary embolism confirmed by spiral computed tomography (CT) pulmonary angiography, showing pulmonary artery obstruction or filling defects involving ≥2 lobes or ≥7 segments (based on a total of 20 pulmonary segments in both lungs). A diagnosis of MPE was made if either criteria was met; (2) Age ≥18 years old; (3) Arterial oxygen saturation ≤90% without evidence of ischemic hypoxic encephalopathy; (4) No obvious heart valvular stenosis or severe valvular calcification; (5) No use of immunosuppressants or glucocorticoids within the previous 6 months; (6) No serious hematological disease within the past 6 months, and no other serious systemic disease or malignancies; (7) No contraindications to vascular puncture or digital subtraction angiography (DSA).

Exclusion criteria: (1) Concomitant central nervous system injury or malignancy; (2) Pregnancy or within 1 week postpartum; (3) Gastrointestinal bleeding within the past 1 month; (4) Major trauma, surgery, or head injury within the past 3 weeks; (5) Recent cardiopulmonary resuscitation; (6) Known conditions associated with a significant risk of bleeding, uncontrolled hypertension, infective endocarditis, or active peptic ulcers; (7) Severe hepatic or renal insufficiency; (8) History of hemorrhagic or ischemic stroke within the past 6 months; (9) Contraindications to thrombolysis or anticoagulation therapy.

A total of 90 eligible patients were ultimately included in the study. According to the treatment modality received, these patients were subsequently allocated to either the combined treatment group (balloon dilatation with thrombectomy) or the basic therapy group (only basic therapy), with 45 cases in each group. The study flow chart is shown in **Figure 1**.

Outcome measures and assessment methods

Primary outcomes: Pulmonary artery pressure (PAP) was assessed by transthoracic echocardiography before treatment and at 72 hours after treatment, including systolic PAP, diastolic PAP, and mean PAP. These indices were estimated based on tricuspid regurgitation velocity, pulmonary valve regurgitation velocity, and the simplified Bernoulli equation [9]. PAP is a key indicator reflecting the severity of pulmonary hemodynamic impairment in MPE and is used to evaluate the effectiveness of the intervention in relieving pulmonary arterial obstruction and improving hemodynamic abnormalities.

The Miller score was used to evaluate the extent of pulmonary vascular obstruction [10].

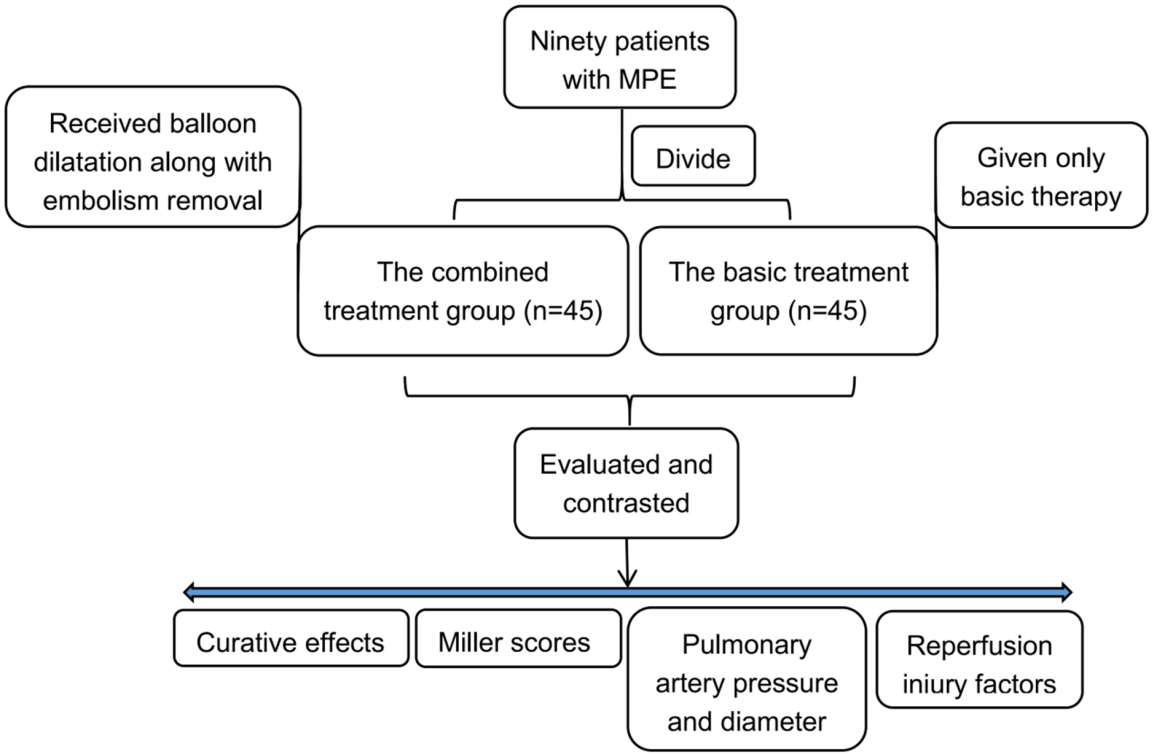

Figure 1. Study flow chart. MPE: massive pulmonary embolism.

(1) Based on pulmonary angiography, one point was assigned for each embolized pulmonary segment. The maximum score was 9 for the right pulmonary artery and 7 for the left pulmonary artery. (2) The degree of obstruction in each lung region was graded as follows: 0 for no obstruction, 1 for moderate obstruction, 2 for severe obstruction, and 3 for complete obstruction, with a maximum score of 9 points for each lung. The total Miller score was calculated as the sum of the above segment and degree scores, ranging from 0 to 34 points, with higher scores indicating more severe embolic burden.

Clinical efficacy was categorized as complete response, marked response, partial response, or no response. Complete response is defined as disappearance of dyspnea and chest pain, normalization of arterial blood gas indices, and normalization of PAP; Marked response is defined as significant improvement in dyspnea and chest pain, substantial correction of hypoxemia to near-normal levels, and a reduction in PAP of >20 mmHg; Partial response is defined as improvement in dyspnea and chest pain, amelioration of hypoxemia toward normal levels, and a reduction in PAP of >10 mmHg; and No response refers to no significant improvement in symptoms, persistent hypoxemia, and a reduction in PAP of <10 mmHg [11]. The overall response rate was calculated as the sum of complete, marked, and partial response rates.

Secondary outcomes: Transthoracic echocardiography was performed prior to treatment and at 72 hours after treatment to assess pulmonary artery diameter (PAD). PAD was measured on echocardiographic images obtained from multiple views, including the parasternal short-axis view of the great vessels and the apical four-chamber view. The inner diameters of the main pulmonary artery and its branches were recorded.

Serum biochemical indicators were detected at different time points: within 6 hours before treatment, and at 1, 6, 12, 24, 48, and 72 hours after treatment. Specifically, myoglobin (MYO) and Troponin T (TnT) were detected using a Roche Cobas e601 automated chemiluminescence immunoanalyzer (chemiluminescence immunoassay); Creatine kinase (CK) was

measured using an automated biochemical analyzer (enzyme kinetic method); Fibrinogen (FIB) was measured using a Sysmex CS-2100i automated coagulation analyzer (thrombin-based turbidimetric method).

Treatment methods

After admission, both groups of patients underwent continuous electrocardiogram monitoring, central venous pressure (CVP) monitoring, and supplemental oxygen by face mask. In addition, expectorants and medications were administered to improve respiratory function as supportive therapy.

Additionally, patients in the basic treatment group received conventional anticoagulation therapy with subcutaneous administration of low-molecular-weight heparin sodium (Qilu Pharmaceutical Co., Ltd.; batch number: 2019-0103) at 5000 IU per dose, every 12 hours.

Patients in combined treatment group received balloon dilatation with mechanical thrombectomy for pulmonary embolism, as detailed below.

The patient was placed supine on the angiography table. After routine disinfection and draping, local anesthesia was administered. The right femoral vein was punctured using the Seldinger technique at the inguinal region, and a 6F catheter sheath was inserted. Right femoral-right iliac-inferior vena cava angiography was performed through the sheath. A guidewire and diagnostic catheter were advanced into the main pulmonary artery for pulmonary angiography (Beijing General Optima IGS 330 medical angiographic X-ray machine). After identification of the thrombus, aspiration thrombectomy was performed using a thrombectomy/aspiration catheter to remove intraluminal thrombi from the pulmonary arteries. Then, a peripheral balloon dilatation catheter (Passeo-35 HP12-40-75, Passeo-35 HP10-80-130; Biotronik) was introduced over the guidewire to dilate the stenotic or occluded pulmonary artery segments, thereby improving pulmonary blood flow. Repeat angiography was performed to ensure successful reperfusion.

To prevent recurrent pulmonary embolism caused by thrombus migration from the lower extremities or inferior vena cava, an inferior vena cava (IVC) filter was implanted as an adjuvant prophylactic procedure. After thrombectomy and balloon dilatation, the catheter was withdrawn while the guidewire was retained. Angiography was repeated through a 5F vascular sheath (Terumo RS*A60K 10SQ). The ostia of the bilateral renal veins were marked at the level of the L1/2 interspace. The filter delivery system was introduced along the guidewire, with the tip of the outer sheath positioned at the inferior border of the renal vein. Under fluoroscopic guidance, the filter was slowly released and deployed in the inferior vena cava. After deployment, contrast medium was injected through the sheath to confirm the filter was in a normal shape and appropriate position. Finally, all devices were removed, and the puncture site was compressed for hemostasis and dressed with an elastic bandage.

Statistical analysis methods

All statistical analyses were performed using SPSS 23.0 software. Continuous variables were presented as mean ± standard deviation. Two-group comparisons were performed using the independent-samples t-test. For comparisons among multiple groups, one-way analysis of variance (ANOVA) was applied, followed by Bonferroni post hoc correction for pair-wise comparisons. Repeated measures ANOVA was used for data comparison over time and between groups, with Bonferroni post-hoc test adopted for pairwise comparisons. Categorical variables were expressed as numbers (n) and percentages (%) and were analyzed using the chi-square test. When the theoretical frequency was between 1 and 5, the chi-square test with continuity correction was applied.

The correlation between reperfusion injury-related markers, right ventricular function indices, and blood gas indices in the combined treatment group at 24, 48, and 72 hours post-treatment was analyzed using Pearson correlation analysis. A P-value <0.05 was considered significant.

Results

Baseline characteristics

No significant differences were observed between the two groups in baseline characteristics, including age, sex, PAP, hemoptysis, etiol-

Table 1. Comparison of baseline characteristics between the two groups

Item	Combined treatment group (n=45)	Basic treatment group (n=45)	t/χ^2	*P*
Sex (male/female, n)	30/15	33/12	0.476	0.490
Age (x ± s, years old)	37.12±7.53	36.85±7.38	0.172	0.864
Hemoptysis symptom (n, %)	15 (33.33%)	13 (28.89%)	0.207	0.649
Cause of disease (n, %)			0.224	0.894
Fracture	23 (51.11%)	22 (48.89%)		
After the procedure	15 (33.33%)	17 (37.78%)		
No obvious cause	7 (15.56%)	6 (13.33%)		
Location of pulmonary embolism (n)			0.959	0.811
Main pulmonary artery	3 (6.67%)	5 (11.11%)		
Right pulmonary artery	18 (40.00%)	16 (35.56%)		
Left pulmonary artery	14 (31.11%)	12 (26.67%)		
Bilateral pulmonary arteries	10 (22.22%)	12 (26.67%)		
Time from onset to treatment (h)	48.56±12.39	47.85±13.54	0.260	0.796

Table 2. Comparison of treatment response between the two groups

Group	Complete response	Marked response	Partial response	No response	Overall response rate
Combined treatment group (n=45)	30 (66.67%)	10 (22.22%)	4 (8.89%)	1 (2.22%)	43 (95.56%)
Basic treatment group (n=45)	18 (40.00%)	8 (17.78%)	10 (22.22%)	9 (20.00%)	37 (82.22%)
χ^2		13.273			5.164
P		0.004			0.023

ogy, location of pulmonary embolism, or time from onset to treatment (all *P*>0.05) (**Table 1**).

Curative efficacy and Miller score

Compared with the basic treatment group, the combined treatment group exhibited significantly higher rates of complete response, marked response, and overall response (all *P*<0.05) (**Table 2**).

Prior to treatment, no significant difference in Miller score was observed between the two groups (23.12±4.38 vs. 23.38±4.07; *P*=0.771). After treatment, the Miller score was significantly lower in the combined treatment group than in the basic treatment group (11.15±3.14 vs. 14.49±4.03; *P*<0.001).

PAP and diameter

No significant differences were observed between groups in PAPs, including systolic, diastolic, and mean PAP, before treatment (all *P*>0.05). After treatment, both groups exhibited significant reductions in PAP compared to baseline, and the combined treatment group showed significantly lower systolic, diastolic, and mean PAP than the basic treatment group (all *P*<0.05) (**Figure 2**).

Similarly, no significant differences were observed in PAD between the two groups prior to treatment (*P*=0.932). After treatment, PAD in the combined treatment group was significantly smaller than that in the basic treatment group (*P*=0.002).

Changes of myocardial injury and inflammation-related indicators

Before treatment and at 1, 24, 48, and 72 hours after treatment, the levels of MYO, TnT, and FIB in both groups changed significantly over time (all *P*<0.05) (**Tables 3** and **4**).

At 24, 48, and 72 hours post-treatment, the levels of MYO, TnT, CK, and FIB were significantly lower in the combined treatment group compared to the basic treatment group (all *P*<0.05). Repeated-measures ANOVA revealed signifi-

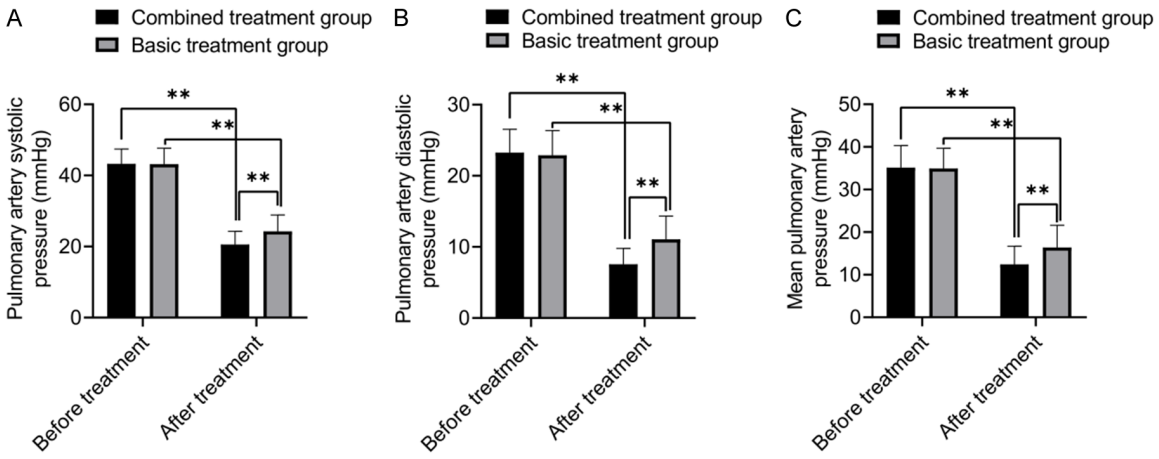

Figure 2. Pulmonary artery pressure. A. Pulmonary artery systolic pressure; B. Pulmonary artery diastolic pressure; C. Mean pulmonary artery pressure. $^{**}P<0.001$.

Table 3. Comparison of MYO and TnT levels between the two groups at different time points

Time	MYO (μg/L)		TnT (μg/L)	
	Combined treatment group (n=45)	Basic treatment group (n=45)	Combined treatment group (n=45)	Basic treatment group (n=45)
Before treatment	74.66±10.08	75.25±10.24	0.12±0.03	0.11±0.02
1 hour after treatment	74.72±9.58	74.75±9.62	0.13±0.03	0.12±0.04
24 hours after treatment	82.38±17.12[a,b]	97.62±17.36[a,b]	0.14±0.04[a]	0.17±0.05[a,b]
48 hours after treatment	88.26±17.55[a,b]	98.79±18.21[a,b]	0.15±0.04[a,b]	0.19±0.05[a,b]
72 hours after treatment	90.52±15.26[a,b,c]	103.15±16.28[a,b]	0.15±0.05[a,b]	0.19±0.06[a,b]
F	11.980	38.940	5.100	31.420
P	<0.001	<0.001	<0.001	<0.001

P<0.05 for [a] vs. Before treatment, [b] vs. 1 hour after treatment, and [c] vs. 24 hours after treatment. MYO: myoglobin; TnT: troponin T.

Table 4. Comparison of CK and FIB levels between the two groups at different time points

Time	CK (U/L)		FIB (mg/L)	
	Combined treatment group (n=45)	Basic treatment group (n=45)	Combined treatment group (n=45)	Basic treatment group (n=45)
Before treatment	68.25±11.25	67.58±12.22	7.03±0.62	6.98±0.75
1 hour after treatment	68.29±11.58	67.63±11.35	7.11±0.68	7.07±0.76
24 hours after treatment	70.21±10.32	75.55±9.38[a,b]	7.41±0.71[a,b]	8.12±0.55[a,b]
48 hours after treatment	71.12±10.03	78.38±10.07[a,b]	7.60±0.62[a,b]	8.95±0.52[a,b,c]
72 hours after treatment	71.26±11.33	80.21±8.52[a,b,c]	7.71±0.54[a,b,c]	9.17±0.66[a,b,c]
F	0.823	14.770	9.804	109.300
P	0.512	<0.001	<0.001	<0.001

P<0.05 for [a] vs. Before treatment, [b] vs. 1 hour after treatment, and [c] vs. 24 hours after treatment. CK: creatine kinase; FIB: fibrinogen.

cant interaction effects, time effects, and between-group effects for all biomarkers in both groups, with trends indicating a gradual increase over time post-treatment ($P<0.05$) (**Table 5**).

Right ventricular function and blood gas parameters

Prior to treatment, no significant difference were observed between groups in right ventric-

Table 5. Temporal trends of MYO, TnT, CK, and FIB in two groups

Statistical value[a]	MYO	TnT	CK	FIB
Interaction effect				
F	5.260	8.329	3.982	28.420
P	<0.001	<0.001	0.004	<0.001
Between-group effect				
F	32.280	20.140	16.190	126.800
P	<0.001	<0.001	<0.001	<0.001
Time effect				
F	46.520	32.690	10.930	93.570
P	<0.001	<0.001	<0.001	<0.001

[a]Comparison of MYO, TnT, CK, and FIB levels between the combined treatment group and the basic treatment group using repeated measures ANOVA. MYO: myoglobin; TnT: troponin T; CK: creatine kinase; FIB: fibrinogen.

ular function or blood gas indices (all $P>0.05$). After treatment, the combined treatment group showed a significantly lower RV/LV ratio compared to the basic treatment group ($P<0.05$) (**Figure 3**).

Correlation analysis

The correlations between myocardial injury biomarkers (MYO, TnT, CK, FIB), right ventricular function indices (LV, RV, RV/LV ratio, MPAd, SVCd), and arterial blood gas parameters (PaO_2, $PaCO_2$) in the combined treatment group were analyzed using Pearson correlation analysis. At 24 hours after treatment, CK levels were negatively correlated with $PaCO_2$ (r=-0.310, P=0.038); at 72 hours after treatment, TnT levels were negatively correlated with PaO_2 (r=-0.353, P=0.017) (**Table 6**).

Discussion

Thrombolytic therapy is commonly used in the treatment of pulmonary embolism; however, it is associated with potential adverse effects, including the release of pro-inflammatory factors, endothelial injury, myocardial damage, and systemic inflammation. In addition, thrombus fragments generated after thrombolysis may cause distal microembolism [12]. These limitations underscore the need for alternative or adjunctive therapeutic strategies that can mitigate such complications.

Compared to the basic treatment group, the combined treatment group exhibited higher treatment response rates, indicating superior efficacy of balloon dilation combined with thrombectomy for the treatment of MPE. The possible mechanisms are as follows: Balloon dilation can directly dilate the narrowed pulmonary artery, restore blood flow, and alleviate pulmonary hypertension. Mechanical thrombectomy removes thrombi, preventing further vascular obstruction. The combined intervention synergistically restores pulmonary arterial patency and enhances hemodynamic recovery. In addition, improving pulmonary circulation reduces right ventricular load and facilitates the recovery of cardiac function, contributing to the recovery of cardiac function and overall clinical improvement. These findings are consistent with previous studies demonstrating that combined treatment exerts superior efficacy for the management of embolic diseases. For instance, Wu et al. [13] demonstrated that percutaneous mechanical thrombectomy combined with balloon angioplasty effectively aspirated renal vein thrombi, successfully dilated stenotic venous lumen, restored renal function, and maintained patency of the ipsilateral deep veins as confirmed by ultrasonography. The findings of the present study are in line with those studies, further validating the benefits of the combined therapy. In summary, the synergistic effect of balloon dilation and thrombectomy achieved superior clinical efficacy in MPE treatment by directly relieving vascular obstruction and optimizing pulmonary circulation.

In the combined treatment group, the Miller score, PAP, and PAD were significantly reduced after treatment. The Miller score is a key indicator for evaluating the severity of pulmonary embolism, whereas PAP and PAD reflect the pulmonary hemodynamic status. These findings suggest that combined treatment can effectively alleviate the severity of pulmonary embolism and improve pulmonary hemodynamics. The possible mechanisms underlying these improvements include the direct removal of thrombi by balloon dilation and thrombectomy, which reduces vascular obstruction and lowers PAP. Restoration of pulmonary circulation reduces right ventricular load and improves cardiac function, which further contributes to the reduction in PAP and PAD.

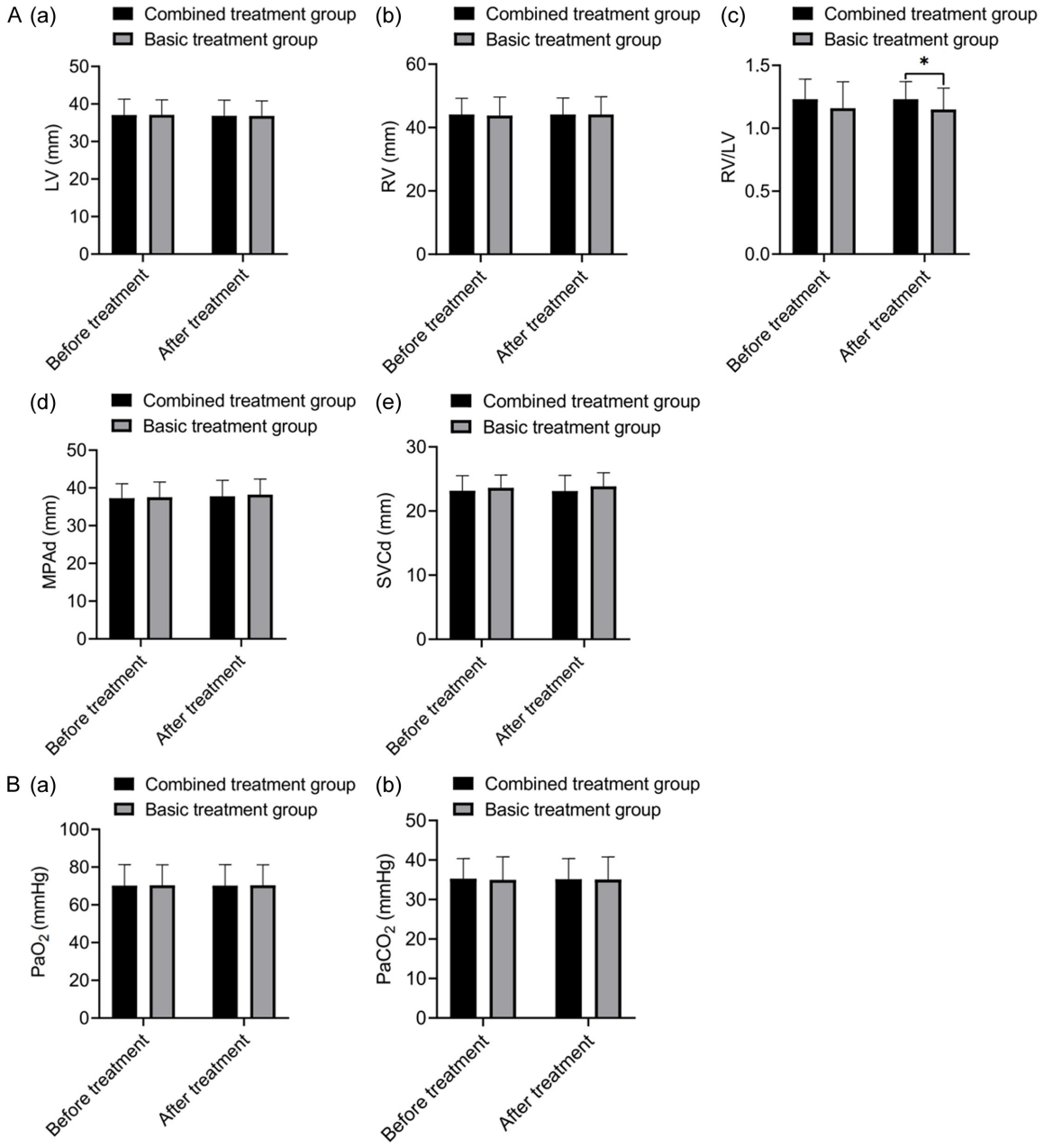

Figure 3. Changes in right cardiac function and blood gas indices before and after treatment. A. Right cardiac function: (a) Left ventricular (LV), (b) Right ventricular (RV), (c) Right ventricular/left ventricular ratio (RV/LV ratio), (d) Main pulmonary artery diameter (MPAd), (e) Superior vena cava diameter (SVCd); B. Blood gas parameters: (a) Partial pressure of oxygen in arterial blood (PaO_2), (b) Partial pressure of carbon dioxide in arterial blood ($PaCO_2$). $^*P<0.05$.

Dynamic changes in MYO, TnT, CK, and FIB levels were observed after treatment. Notably, the levels of these indicators in the combined treatment group were significantly lower at key time points, indicating that combined treatment exerts a protective effect against myocardial injury and inflammation. MYO can trigger local inflammatory responses following myocardial injury [14], whereas TnT serves as a specific biomarker of myocardial injury. Myocardial injury can induce systemic inflammatory responses and oxidative stress [15]. CK reflects skeletal and cardiac muscle injury, which can alter local inflammatory and oxidative stress states [16]. FIB plays a pivotal role in inflammatory responses: during infection and inflammation, inflam-

Table 6. Correlation between myocardial injury markers, right ventricular function indices, and arterial blood gas indices

Item		LV	RV	RV/LV ratio	MPAd	SVCd	PaO_2	$PaCO_2$
24 h after treatment								
MYO	r	-0.100	-0.159	-0.065	0.023	-0.038	0.182	-0.013
	P	0.514	0.296	0.673	0.882	0.802	0.232	0.934
TnT	r	0.051	0.224	0.133	-0.241	0.160	0.158	0.259
	P	0.738	0.139	0.383	0.110	0.293	0.299	0.085
CK	r	-0.149	0.007	0.148	0.226	0.030	0.053	-0.310
	P	0.330	0.964	0.333	0.135	0.843	0.729	0.038
FIB	r	0.002	0.177	0.144	0.021	0.148	-0.211	0.068
	P	0.990	0.244	0.346	0.894	0.330	0.164	0.658
48 h after treatment								
MYO	r	-0.185	-0.085	0.079	0.043	-0.150	0.004	-0.223
	P	0.225	0.577	0.604	0.779	0.327	0.980	0.142
TnT	r	-0.045	0.015	0.016	0.014	0.165	-0.156	-0.022
	P	0.771	0.922	0.916	0.928	0.277	0.305	0.888
CK	r	-0.006	0.109	0.103	0.163	0.173	0.030	-0.172
	P	0.968	0.475	0.501	0.286	0.257	0.846	0.258
FIB	r	0.014	0.042	0.022	-0.062	-0.087	-0.007	0.017
	P	0.929	0.784	0.886	0.686	0.570	0.966	0.914
72 h after treatment								
MYO	r	0.231	-0.095	-0.234	-0.262	0.239	-0.207	-0.163
	P	0.127	0.537	0.121	0.082	0.113	0.173	0.283
TnT	r	0.066	-0.107	-0.138	0.045	0.082	-0.353	0.157
	P	0.667	0.485	0.367	0.768	0.590	0.017	0.304
CK	r	0.082	0.200	0.083	0.227	0.113	0.101	0.069
	P	0.594	0.187	0.587	0.133	0.458	0.508	0.651
FIB	r	0.178	0.063	-0.083	0.149	-0.018	-0.004	-0.032
	P	0.243	0.679	0.586	0.330	0.907	0.977	0.836

MYO: myoglobin; TnT: troponin T; CK: creatine kinase; FIB: fibrinogen; LV: left ventricular; RV: right ventricular; RV/LV: right ventricular/left ventricular; MPAd: main pulmonary artery diameter; SVCd: superior vena cava diameter; PaO_2: partial pressure of oxygen in arterial blood; $PaCO_2$: partial pressure of carbon dioxide in arterial blood.

matory cells release cytokines to promote hepatic synthesis of FIB, and the interaction between FIB and inflammatory cells exacerbates inflammatory reactions. Under conditions of oxidative stress, ROS can damage vascular endothelial cells and drive the synthesis and release of FIB; furthermore, FIB can interact with platelets to facilitate thrombosis, which further exacerbates tissue ischemia, hypoxia, and oxidative stress [17]. The downregulation of these biomarkers in the combined treatment group may be associated with rapid restoration of pulmonary blood flow, which shortens myocardial ischemia duration and mitigates ischemic injury. Additionally, combined treatment may inhibit the release of myocardial injury and inflammation-related factors through modulation of inflammatory and oxidative stress pathways. Zhang et al. [18] demonstrated that multiple mechanisms, including improved pulmonary circulation, reduced inflammation, and alleviated oxidative stress, can confer anti-atherosclerotic effects, and the findings of the present study also corroborate this perspective.

After treatment, the RV/LV ratio in the combined treatment group was significantly lower than that in the basic treatment group, suggesting a reduction in right ventricular load. Several mechanisms may contribute to this effect: (1) restoration of pulmonary arterial patency and blood flow reduces PAP and right ventricular afterload, lowering the RV/LV ratio;

(2) alleviation of right ventricular dysfunction improves right ventricular blood perfusion and oxygen supply, promoting functional recovery and reducing right ventricular dilation; (3) optimization of cardiopulmonary interaction enhances pulmonary circulation and reducing pulmonary congestion, which in turn improves left ventricular function and indirectly modulates right ventricular function to decrease the RV/LV ratio; (4) reduction of inflammation and oxidative stress protects cardiopulmonary tissues by decreasing thrombus load, restoring the normal structure and function.

Collectively, combined treatment exerts a multifaceted protective effect in patients with MPE by alleviating the severity of pulmonary embolism, optimizing pulmonary hemodynamics, downregulating the levels of myocardial injury and inflammation-related indicators, and reducing right ventricular load. These therapeutic effects may be mediated by the improvement of pulmonary circulation and the effective regulation of inflammatory and oxidative stress responses.

We further investigated the correlation between myocardial injury biomarkers (MYO, TnT, CK, FIB), right ventricular function parameters (LV, RV, RV/LV ratio, MPAd, SVCd), and arterial blood gas indices (PaO_2, $PaCO_2$) in the combined treatment group. CK at 24 hours post-treatment was negatively correlated with $PaCO_2$; and TnT at 72 hours post-treatment was negatively correlated with PaO_2. These findings indicate that, in patients undergoing balloon dilation combined with thrombectomy, myocardial injury markers are closely associated with right cardiac function and arterial blood gas parameters. The underlying mechanisms for these negative correlations may be attributed to the close cardiopulmonary interaction and the cascade effects of myocardial injury on respiratory and circulatory function. On the one hand, elevated CK levels at 24 hours reflect acute myocardial damage caused by MPE-induced ischemia and hypoxia; severe myocardial injury impairs cardiac contractility and reduces cardiac output, which in turn leads to decreased alveolar ventilation-perfusion matching and inefficient carbon dioxide exhalation, resulting in elevated $PaCO_2$ [19]. On the other hand, TnT is a specific marker of myocardial injury, and its elevated expression at 72 hours indicates persistent myocardial damage; impaired right cardiac function caused by severe myocardial injury further exacerbates pulmonary circulatory disturbance, reduces pulmonary oxygen exchange efficiency, and leads to a decrease in PaO_2, accounting for the negative correlation between TnT and PaO_2 [20].

Previous studies have also demonstrated that reperfusion injury can affect cardiac function and increase the levels of myocardial injury markers such as CK and TnT. For instance, Bei et al. [21] confirmed that myocardial injury exerts a remarkable influence on cardiac function, while alterations in cardiac function in turn influence blood gas parameters. Alterations in blood gas indices might reflect changes in pulmonary function, which is closely associated with the severity of pulmonary embolism. Wang et al. [22] highlighted the importance lung function assessment in evaluating pulmonary embolism severity. Therefore, the correlation between myocardial injury markers and blood gas indices may indirectly reflect the disease progression of pulmonary embolism. The negative correlations between CK and $PaCO_2$ as well as between TnT and PaO_2 reflect the integrated effect of myocardial injury on cardiopulmonary function in MPE patients.

This study has several limitations. First, the sample size was relatively small, which may introduce biases the generalizability of the findings. Future studies should expand the sample size to improve the reliability of the results. Second, no long-term follow-up was performed, preventing evaluation of the sustained efficacy of combined treatment. Subsequent studies should incorporate extended follow-up periods to address outcomes such as recurrence rates and long-term survival. Third, this study primarily investigated correlations between myocardial injury markers, right ventricular function, and blood gas indices, without exploring the underlying molecular mechanisms. Further research integrating clinical observations with basic experimental studies is warranted to elucidate the molecular mechanism of myocardial injury.

Conclusion

Balloon dilation combined with thrombectomy for the treatment of MPE can reduce myocardial injury and inflammation-related markers, decrease Miller scores, and lower PAP and PAD, thereby significantly improving the clinical out-

comes. Despite these promising results, inherent limitations exist and require further in-depth research for improvement.

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Disclosure of conflict of interest

None.

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