Improved Outcome of Surgical Pulmonary Embolectomy by Aggressive Intervention for Critically Ill Patients

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Background. **Acute massive pulmonary thromboembolism is a life-threatening disorder, and prompt treatment is necessary. We analyzed the outcome of pulmonary embolectomy for massive pulmonary embolism.**

Methods. **Nineteen patients who underwent pulmonary embolectomy were retrospectively investigated. Average age of patients was 59 years, and 79% were female. Most patients had massive or submassive pulmonary thromboemboli dislodging into the main pulmonary trunk or bilateral main pulmonary arteries. Hemodynamics of most patients were unstable. Two patients required percutaneous cardiopulmonary support before embolectomy, and 4 required cardiopulmonary resuscitation. In 6 patients, thrombolysis was ineffective.**

Results. **All patients underwent emergent pulmonary embolectomy. Operative mortality was 5.3%. No patients exhibited newly developed neurologic damage. Ten-year survival rate was 83.5% ± 8.7%.**

Conclusions. **Pulmonary embolectomy saves critically ill patients having acute massive pulmonary thromboembolism. We must evaluate pulmonary embolism patients with an algorithm that includes surgical embolectomy as one of several therapeutic options.**

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Pulmonary thromboembolism (PTE) has wide spectrum of clinical pictures depending on the chronologic and spatial distribution of embolus in the pulmonary arteries. Its prognosis varies significantly depending on whether the emboli obstruct the proximal pulmonary trunk or small peripheral pulmonary arteries and whether the process of the arterial occlusion is acute or chronic. Surgical pulmonary embolectomy for acute PTE was introduced by Trendelenburg in 1908 [1]. It had been a very difficult procedure associated with extremely high mortality. Owing to John Gibbon's contribution to development of the heart-lung machine, Cooley and colleagues [2] reported the initial successful case of pulmonary embolectomy using cardiopulmonary bypass. They also developed a portable heart-lung machine as an aid for bridge to surgical embolectomy for critically ill patients. After the advent of fibrinolytic therapy in the 1970s, critiques for surgical embolectomy emerged because of high mortality after surgical embolectomy [3–6]. However, surgical embolectomy had been revived recently because of progress in diagnostic modalities and cardiopulmonary support. The objective of this study is to analyze the outcome of surgical pulmonary embolectomy retrospectively.

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Patients and Methods

Nineteen patients undergoing pulmonary embolectomy among 133 patients (14.2%) who had acute PTE during 21 years in two medical institutes (from 1988 to 2002 in Tsukuba Medical Center and from 2002 to 2009 in Hirosaki University Hospital) were analyzed retrospectively. Consent for the study was granted by the Hirosaki University Ethical Committee; individual consent for this specific study was waived.

These 133 patients were referred to a single cardiovascular surgery team for management of acute PTE. Discussion between cardiovascular surgeons and doctors in charge of underlying disorders was made to choose the best and most secure treatment to save the patients. The decision for pulmonary embolectomy was made considering patients' hemodynamics, risk of bleeding while receiving thrombolytic therapy, and prognosis of original disorders. The diagnosis was made under strong suspicion of acute PTE for patients who had sudden onset of circulatory collapse or unexpected chest symptoms including chest pain, tachypnea, and tachycardia. Some patients were diagnosed as PTE on the bedside echocardiography after in-hospital emergency call for cardiopulmonary arrest or collapse. Definitive diagnosis was made by radiologic findings as follows: filling defect in pulmonary arteries in the pulmonary angiogram or the enhanced computed tomography (CT) scan. Right ventricular dilation on echocardiogram or enhanced CT scan was considered as important sign for massive or submassive pulmonary embolism. Patients who had chronic

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pulmonary embolism with severe pulmonary hypertension were excluded from this analysis.

Among 133 patients having PTE, there were 49 patients having massive or submassive pulmonary embolism managed by nonsurgical treatment. In these patients, thrombolytic therapy was performed in 25 patients, inferior vena cava (IVC) interruption with or without anticoagulant therapy in 22 patients (IVC plication in 4, IVC filter in 18) and only observation in 6 patients. Seven patients died of PTE, and 3 patients died owing to their original disorder. Mortality in the medical treatment group was 20.4% (10 of 49), and mortality due to PTE was 15.2% (7 of 46). Among these 7 patients, 3 died immediately after onset of PTE, and 4 patients were excluded from surgical embolectomy because irreversible brain damage had occurred owing to delayed notification to the surgical team.

Progress of diagnostic modalities such as multidetector CT scan, screening of PTE using transthoracic echocardiography, and an interest in PTE as a medicolegal issue for in-hospital patients made physicians notify the cardiovascular group early when PTE was suspected. Our recent algorithm of management for acute pulmonary embolism is shown in Figure 1. In the pulmonary embolectomy group, there were 4 men and 15 women. Mean age of patients was 59 ± 16 years. Predisposing factors for venous thromboembolism are shown in Table 1. Indication for pulmonary embolectomy was deep shock requiring percutaneous cardiopulmonary support (PCPS) in 2 patients, cardiopulmonary resuscitation in 4 patients, and contraindication or high risk for thrombolysis in 16 patients (4 postcraniotomies, 5 recent strokes, 1 multiple trauma including head and vertebral column, 3 pregnancies, 3 post-major abdominal surgery). Six patients were in the neurology/neurosurgical ward, 3 in the orthopedics ward, and 4 in the gyneco-obstetrics ward. One patient who had acute myocardial infarction with severe pulmonary congestion was on the way to recovery by coronary artery intervention.

Table 1. Patient Characteristics and Background

Patient Characteristics	Range	Mean ± SD
Age, years	27–85	58.6 ± 16.8
Sex, male/female, n	4/15	
Onset		
Out of hospital, n	5	
In hospital, n	14	
Time from initial presentation to operation, hours	1–24	11.1 ± 9.9
EuroSCORE, logistic, %	9.1–56.7	23 ± 12
PESI	86–238	174 ± 53
Predisposing factor, n (%)		
Long-term bed rest, ≥5 days	13	(68.4)
Major surgery	8	(42.1)
Stroke	5	(26.3)
Cancer	2	(10.5)
Trauma	3	(15.8)
Brain tumor	2	(10.5)
Pregnancy	3	(15.8)

EuroSCORE = European System for Cardiac Operative Risk Evaluation; PESI = Pulmonary Embolism Severity Index [8].

Emergent pulmonary embolectomy was considered for all patients with circulatory collapse or deep shock due to acute massive PTE, or patients having large proximal PTE and having high risk for fibrinolytic therapy. Involvement of pulmonary artery occlusion was evaluated using the pulmonary artery involvement score proposed by

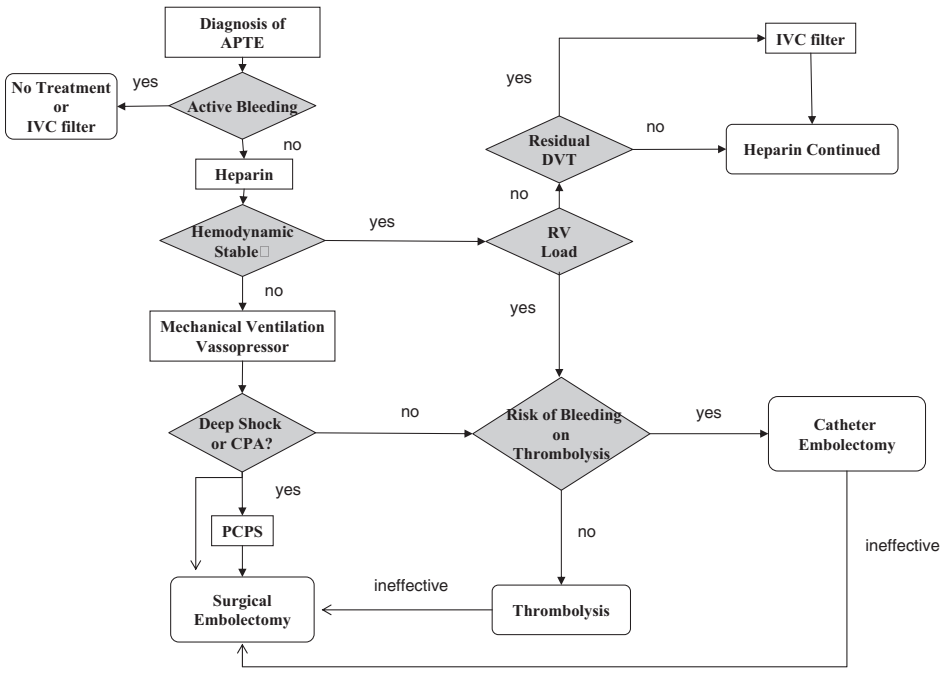

Fig 1. Algorithm of management for acute pulmonary thromboembolism (APTE). (CPA = cardiopulmonary arrest; DVT = deep venous thrombosis; IVC = inferior vena cava; PCPS = percutaneous cardiopulmonary support; RV = right ventricle.)

Table 2. Preoperative Condition and Mortality in Each Group

Preoperative Condition	n	Death	Mortality
Shock without CPA	11	0	0%
CPA	4	0	0%
Preoperative PCPS	2	0	0%
Failed thrombolysis	6	1[a]	16.6%
Pulmonary artery involvement			
Miller index (involvement) >12	18	1[a]	5.5%
Miller index (involvement) ≤12	1	0	0%
PESI class			
III	2	0	0%
IV	1	0	0%
V	16	1[a]	6.3%

Shock is indicated by systolic blood pressure less than 80 mm Hg or shock index (heart rate/systolic blood pressure) more than 1. [a] Same patient.

CPA = cardiopulmonary arrest; PCPS = percutaneous cardiopulmonary support; PESI = Pulmonary Embolism Severity Index.

Miller and colleagues [7]. Predicted operative mortality was calculated using the logistic European System for Cardiac Operative Risk Evaluation. Severity of PTE was evaluated by the Pulmonary Embolism Severity Index score, and risk of death was classified to five groups according to the index score [8]. Simply described, classes I and II represent low-risk groups whereas classes III to V indicate high-risk groups.

Surgical Technique

All patients underwent emergent pulmonary embolectomy through median sternotomy using cardiopulmonary bypass. Arterial cannula was placed into the ascending aorta or the femoral artery. Venous drainage was performed by bicaval cannulation. Mild or moderate hypothermic cardiopulmonary bypass was employed. Six patients underwent pulmonary embolectomy under aortic cross-clamping, and 13 patients underwent operation under beating heart. A left atrial vent was used in 3 patients in whom a peripheral pulmonary embolus was to be extracted. The pulmonary trunk was incised longitudinally and the embolus at the pulmonary artery bifurcation to bilateral main pulmonary arteries was gently extracted by forceps. Thrombus in the left main pulmonary artery and lobar arteries was extracted and aspirated through this incision. An additional incision on the right main pulmonary artery was performed under aortic cross clamp if the peripheral thrombus in the right pulmonary arteries were to be removed. Pulmonary arteriotomy was secured by 5-0 monofilament suture.

Postoperative Anticoagulant Regimen

Postoperative anticoagulant therapy using unfractionated heparin was commenced immediately after the risk of surgical site bleeding disappeared. For patients who had a risk of bleeding such as stroke or injury of spine, anticoagulant therapy was withheld, and interruption of the IVC was employed.

Results

For 18 of the 19 patients, definitive diagnosis of PTE was made by pulmonary angiogram (n = 5), enhanced CT (n = 13), or both (n = 1). One patient who had hip joint replacement and had cardiopulmonary arrest in the rehabilitation ward underwent emergent pulmonary embolectomy without pulmonary angiogram and CT. In this patient, acute PTE was suspected by right ventricular dilation on echocardiogram, and definitive diagnosis of PTE was made during surgical embolectomy. Eighteen patients had massive PTE on the pulmonary trunk and bilateral main pulmonary arteries, whereas 1 patient after cesarean section with deep shock had occlusion of the right main pulmonary artery. One patient had floating right heart emboli on echocardiogram. Transthoracic echocardiography or transesophageal echocardiography was performed in 17 patients, and they exhibited right ventricular dilation and left ventricular collapse. In 1 patient, echocardiography exhibited right ventricular dilation and hypertrophy. Eight patients were transported from other medical facilities by ambulance or helicopter.

Preoperative hemodynamics were unstable in 17 patients (Table 2). Four patients required cardiopulmonary resuscitation at onset of acute PTE. Nine patients were on ventilator, and 2 patients were on PCPS. Although doctors were aware of the high risk of bleeding, 6 patients had received fibrinolytic therapy as an initial treatment for massive PTE before pulmonary embolectomy, but it was ineffective. Catheter embolectomy was attempted in 3 patients, but it was discontinued because of deteriorated hemodynamic state during procedure. Average Miller involvement score was 13.9 ± 1.3, ranging from 11 to 16. All patients belonged to Pulmonary Embolism Severity Index class III or higher, indicating they had high-risk PTE.

Surgical outcomes were shown in Table 2 and 3. No patient in preoperative shock, cardiopulmonary arrest requiring cardiopulmonary resuscitation, on PCPS died.

Table 3. Surgical Mortality and Morbidity

Surgical Mortality and Morbidity	n	Incidence
Hospital mortality	1[a]	5.3%
Neurologic damage	0	0%
Major bleeding complication	2	10.5%
Postoperative PCPS	1[a]	5.3%
Renal dysfunction	1[a]	5.3%
Blood transfusion	14	73.7%
Postoperative ICU stay, days (range)	1–18	(4.2 ± 5.0)
Long-term outcome		
Ten-year survival		83.5% ± 8.7%
Death due to neoplasm	2	
Cardiovascular event	1	
PTE recurrence or chronic PTE	0	

[a] Same patient.

ICU = intensive care unit; PCPS = percutaneous cardiopulmonary support; PTE = pulmonary thromboembolism.

One patient died on postoperative day 4 of intractable pulmonary hemorrhage after embolectomy. This patient underwent attempted catheter embolectomy and local thrombolysis before surgical embolectomy. Echocardiography exhibited not only right ventricular dilation but also hypertrophy. Because the thrombi were mixed with fresh and old ones, extensive thrombectomy beyond the right upper lobe artery was necessary in this patient. Postoperative PCPS was necessary in this patient for hypoxemia. Early and hospital mortality of pulmonary embolectomy was 5.3%. Among 3 patients with PTE during pregnancy, 1 occurred after cesarean section, and the other 2 occurred during pregnancy. One patient underwent pulmonary embolectomy under cardiopulmonary bypass and intraaortic balloon pumping during the second trimester of pregnancy, and the patient delivered a healthy child at full term. Details of the former patient were documented in our previous report [9]. Another patient at the third trimester of pregnancy underwent cesarean section under use of PCPS and pulmonary embolectomy simultaneously. Fifteen patients underwent insertion of an IVC filter perioperatively (6 temporary filters, 9 permanent filters), and 1 patient underwent partial ligation of IVC on the seventh day after pulmonary embolectomy. No patient exhibited postoperative neurologic damage or exacerbation of neurologic symptom. Two patients had major bleeding complication after operation. One who underwent pulmonary embolectomy for failed thrombolysis had intraoperative massive pulmonary bleeding. The other patient, who had a history of laminoplasty for cervical axial injury and contusion head injury, had subarachnoidal hemorrhage at day 4 after pulmonary embolectomy. In this patient, administration of heparin was discontinued, and the patient recovered without neurologic complication.

Long-Term Survival

Average follow-up period was 48 ± 61 months, ranging from 8 to 180. Two patients died of neoplasm during follow-up. Kaplan-Meyer survival analysis revealed 10-year survival rate was 83.5% ± 8.7%. No patients showed symptoms of chronic pulmonary hypertension such as dyspnea or palpitations. One patient underwent replacement of the ascending aorta and the aortic arch successfully for acute aortic dissection occurring at 10 years after pulmonary embolectomy. Enhanced CT exhibited normal pulmonary artery in this patient.

Comment

Acute PTE has wide spectrum of clinical pictures, from sudden, devastating circulatory collapse to subtle dyspnea or chest pain. In some patients, it is asymptomatic. This is because the pulmonary vascular bed has sufficient reserve capacity, and pulmonary arteries per se have spontaneous fibrinolytic potentials. The prognosis of PTE depends on spatial distribution of emboli and chronology of pulmonary artery occlusion. In the Management Strategies and Prognosis of Pulmonary Embolism study, the mortality of patients with PTE having cardiopulmonary arrest at onset was as high as 65% [10], whereas that of patients having no shock and no right ventricular overload was 6%. Acute occlusion of major pulmonary arteries induces sudden reduction of effective vascular area and steep increase of pulmonary vascular resistance. That will increase right ventricular afterload and induces right ventricular dysfunction combined with right ventricular ischemia. Reduced right ventricular output induces decrease of left ventricular preload and hypotension. Occlusion of the pulmonary artery also causes ventilation-perfusion mismatch, resulting in hypoxia. Sympathetic nerve reflex may also cause syncope at onset. In cases of massive PTE, sudden deterioration of circulatory and respiratory function frequently causes circulatory collapse or cardiopulmonary arrest.

In the era without cardiopulmonary support, mortality of surgical embolectomy was extremely high. Although the first successful case of surgical embolectomy was reported by Kirshner in 1924 [11], only 23 patients were known to have been salvaged before the 1960s. Cooley and Beall [2] reported the first successful surgical embolectomy using extracorporeal circulation in 1961. Since then, improved outcomes of pulmonary embolectomy has been reported. Most patients having massive pulmonary embolism die within 24 hours after onset [12]. Long-term right ventricular load may cause right ventricular ischemia and right ventricular failure. Goldhaber and colleagues [13] showed risk factors for death within 3 months after onset of PTE were more than 70 years of age, cancer, congestive heart failure, chronic obstructive pulmonary disease, hypotension, tachypnea, and right ventricular hypokinesis on echocardiography.

Although surgical embolectomy is invasive, prompt removal of emboli decreases right ventricular afterload and promotes quick recovery if surgery is performed emergently. Stein and colleagues [14] analyzed 1,300 cases of pulmonary embolectomy collected from 46 reports from 1961 to 2006. They showed that for patients operated on before 1985, the average mortality was 32%, whereas it was 20% for patients operated on from 1985 to 2005. Operative mortality for patients who experienced cardiac arrest before pulmonary embolectomy was as high as 59%, compared with 29% for patients who did not have preoperative cardiac arrest. Leacche and colleagues [15] reported 47 patients who underwent embolectomy with operative mortality of 6% and 3-year survival of 83%. The high survival rate can be attributed to improved surgical technique, rapid diagnosis and triage, and careful patient selection. Kandar and colleagues [16] reported excellent surgical outcome for 25 critically ill massive PTE patients with operative mortality of 8%. Our study involved many hemodynamically compromised patients, including 2 patients with preoperative cardiopulmonary support. Although our study involved only 19 patients during a long-term period, both short-term and long-term outcomes were excellent.

In the guidelines on the diagnosis and management of acute pulmonary embolism from the European Heart Association, surgical pulmonary embolectomy for acute

PTE was reevaluated as an effective alternative treatment of patients for whom thrombolysis was contraindicated owing to massive pulmonary embolism or of patients who were refractory to medical management [17]. Meneveau and colleagues [18] reported that surgical embolectomy led to a better in-hospital course for patients with massive PTE who had not responded to thrombolysis. Although patients with massive pulmonary embolism unresponsive to thrombolysis have risk of bleeding, rescue pulmonary embolectomy is justified because there is no effective alternative procedure to save these severely ill patients.

The idea of portable cardiopulmonary bypass was proposed by Cooley and colleagues [2] as early as the 1960s. Surprisingly, their system consisted of a revolutionary system weighing 40 pounds despite being at the early era of development of the cardiopulmonary bypass. Contemporary cardiopulmonary circuits and oxygenators have become more compact and biocompatible. The centrifugal pump is driven by battery for several hours. Percutaneous insertion of arterial and venous cannulas became safe under guidance of ultrasonography. Therefore, use of PCPS as a bridge to pulmonary embolectomy became an important option for management of acute massive PTE [19, 20]. Medicolegal issues are involved in PTE occurring in hospitalized patients. Venous thromboembolism, including PTE, is a preventable complication among hospitalized patients. However, prophylaxis against venous thrombolism is not completely effective. Therefore, management to save patients having PTE is also important. Transportation of critically ill patients to a cardiac center is becoming rapid by the use of airborne ambulances. The management technique for patients in shock due to acute massive PTE has became more sophisticated recently [17]. Therefore, critically ill patients having PTE have a chance to survive by surgical embolectomy.

In conclusion, pulmonary embolectomy saves critically ill patients having acute massive PTE. Surgical embolectomy is very effective for selected highly compromised patients with high bleeding risk for thrombolysis, failed thrombolysis, or insufficient time for systemic thrombolysis to be effective. We must evaluate pulmonary embolism patients with an algorithm that includes surgical embolectomy as one of several therapeutic options.

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INVITED COMMENTARY

Fukuda and colleagues [1] have revisited an old, but recurring challenge, which is the best strategy for management of patients with pulmonary embolism. Although they have dusted off some old patient records to present this retrospective review, they thoughtfully remind our community that surgical pulmonary embolectomy remains a lifesaving procedure.

The authors create relevance with this work by adding

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