Surgical Pulmonary Embolectomy Outcomes for Acute Pulmonary Embolism

Jae Hwan Choi, MD, Thomas J. O'Malley, MD, Elizabeth J. Maynes, MD, Matthew P. Weber, MS, Nicholas D. D'Antonio, BS, Martín Mellado, MD, Frances M. West, MD, Taki Galanis, MD, Carin F. Gonsalves, MD, Gregary D. Marhefka, MD, Bharat K. Awsare, MD, Geno J. Merli, MD, and Vakhtang Tchantchaleishvili, MD

Division of Cardiac Surgery, Thomas Jefferson University, Philadelphia, Pennsylvania; Faculty of Medicine, University of Chile, Santiago, Chile; Division of Critical Care, Pulmonary/Allergy, and Immunology, Thomas Jefferson University, Philadelphia, Pennsylvania; Department of Surgery, Thomas Jefferson Vascular Center, Thomas Jefferson University, Philadelphia, Pennsylvania; Division of Vascular and Interventional Radiology, Thomas Jefferson University, Philadelphia, Pennsylvania; and Division of Cardiology, Thomas Jefferson University, Philadelphia, Pennsylvania

Background. **Acute pulmonary embolism (PE) is associated with significant mortality. Surgical embolectomy is a viable treatment option; however, it remains controversial as a result of variable outcomes. This review investigates patient outcomes after surgical embolectomy for acute PE.**

Methods. **An electronic search was performed to identify articles reporting surgical embolectomy for treatment of PE. 32 studies were included comprising 936 patients. Demographic, perioperative, and outcome data were extracted and pooled for systematic review.**

Results. **Mean patient age was 56.3 years (95% confidence interval [CI], 52.5, 60.1), and 50% were male (95% CI, 46, 55); 82% had right ventricular dysfunction (95% CI, 62, 93), 80% (95% CI, 67, 89) had unstable hemodynamics, and 9% (95% CI, 5, 16) experienced cardiac arrest. Massive PE and submassive PE were present in 83% (95% CI, 43, 97)] and 13% (95% CI, 2, 56) of patients, respectively. Before embolectomy, 33% of patients (95% CI, 14, 60) underwent systemic thrombolysis, and 14% (95% CI, 8, 24) underwent catheter embolectomy. Preoperatively, 47% of patients were ventilated (95% CI, 26; 70), and 36% had percutaneous cardiopulmonary support (95% CI, 11, 71). Mean operative time and mean cardiopulmonary bypass time were 170 minutes (95% CI, 101, 239) and 56 minutes (95% CI, 42, 70), respectively. Intraoperative mortality was 4% (95% CI, 2, 8). Mean hospital and intensive care unit stay were 10 days (95% CI, 6, 14) and 2 days (95% CI, 1, 3), respectively. Mean postoperative systolic pulmonary artery pressure (sPAP) was significantly decreased from the preoperative period (sPAP 57.8, mm Hg; 95% CI, 53, 62.7) to the postoperative period (sPAP, 31.3 mm Hg; 24.9, 37.8); $P < .01$). In-hospital mortality was 16% (95% CI, 12, 21). Overall survival at 5 years was 73% (95% CI, 64, 81).**

Conclusions. **Surgical embolectomy is an acceptable treatment option with favorable outcomes.**

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Pulmonary embolism (PE) has become a prominent clinical condition associated with high morbidity and mortality.[1] Currently, the incidence of acute PE in the United States represents 600,000 cases annually, which accounts for 50,000 to 200,000 deaths.[2] Given what appeared to be a public health crisis, the surgeon general made a call to action in 2008 for a public health response to deep vein thrombosis (DVT) and PE.[3] As part of this, clinicians have been examining best practices related to these clinical conditions and have been searching for means to reduce morbidity and mortality related to DVT and PE. Hospitals are rapidly developing PE response teams to address a growing clinical concern toward improving patient outcomes, clinical decision making, and treatment approaches.[4] Intervention for acute PE has largely focused on anticoagulation, systemic thrombolytic agents, catheter-directed thrombolytic agents and embolectomy, and surgical embolectomy.

Given that most deaths from PE occur within the first few hours after the inciting event, recognition of these risk factors can allow clinicians to assess patients rapidly

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Address correspondence to Dr Tchantchaleishvili, Division of Cardiac Surgery, Thomas Jefferson University, 1025 Walnut St, Ste 607, Philadelphia, PA 19107; email: vakhtang.tchantchaleishvili@jefferson.edu.

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for DVT and PE and begin treatment to prevent clinical worsening and death.[5] Despite advances in diagnostic modalities and interventions, mortality of acute PE remains high, with an international registry of 2454 patients noting a 17.4% mortality rate after PE.[6] This mortality rate is divided by type of clinical presentation: massive PE, which causes arterial hypotension and cardiogenic shock and has an in-hospital mortality rate of 25% to greater than 50%[7,8]; and submassive PE, which manifests with normotension and has a 3% to 15% in-hospital mortality rate.[9] Treatment for PE focuses on preventing clot propagation with anticoagulation and reducing the clot burden that contributes to right ventricular overload, which can lead to cor pulmonale. Current therapeutic interventions attempt to reduce clot size through systemic or catheter-directed thrombolysis or by removing the clot entirely with suction embolectomy or surgical embolectomy. These approaches are used in a progressive pattern, depending on the clinical situation, where significant hemodynamic compromise or failure of thrombolytic or catheter-directed embolectomy favors surgical embolectomy.

Surgical embolectomy has evolved significantly since Trendelenburg's approach in the early 20th century, when the operation was performed without the use of cardiopulmonary bypass.[10] Dr. Martin Kirschner, a pupil of Tredelenburg, was the first to perform the embolectomy successfully with this approach in 1924.[10] However, it was not until 1960s, with the advent of cardiopulmonary bypass, and promotion by surgeons Cooley, Beal, and Alexander, that the outcomes improved from their initial dismal levels.[11] Despite these improvements, the treatment of this deadly condition continued to have high mortality rates into the late 20th century.[10] In examining the outcomes of this procedure, Kilic and colleagues[12] evaluated 2700 patients through the Nationwide Inpatient Sample who underwent surgical embolectomy for acute PE from 1999 to 2008. This study demonstrated a 27.2% mortality rate after pulmonary embolectomy. A more recent evaluation of the Nationwide Inpatient Sample with respect to surgical embolectomy by Alqahtani and colleagues[13] noted that early surgical embolectomy operations, performed between 2003 and 2009 in their study, had a 23.1% inpatient mortality rate, whereas later operations, performed from 2009 to 2014, had a 14% mortality rate, thus suggesting perhaps that mortality rates are improving with modern treatment.

Given its invasive nature, surgical embolectomy was typically reserved for severe cases or as a final line of defense. Previously, this procedure had high mortality in its early cases and through the 1990s with rates from 23% to 46%.[9,14] However, in the early 2000s and into the 2010's, more recent studies have been reporting in-hospital mortality as low as 5% to 6%.[15-17]

When alternatives fail, surgical embolectomy becomes necessary to alleviate the hemodynamic compromise related to massive PE. Some centers, however, approach surgical embolectomy before the onset of hemodynamic collapse in lieu of performing this operation as a salvage measure. Thus, there is great variability among centers in choosing the threshold of surgical intervention.

Earlier recommendations that surgical embolectomy be delayed until after thrombolysis and the institution of medical management may unnecessarily delay definitive treatment in patients that may benefit from surgical embolectomy. More recent literature suggests that early surgical embolectomy in patients with impending circulatory collapse demonstrates positive results.[15,17] With improving surgical technique and care over the past several decades, surgical embolectomy has become an important tool in the armamentarium of clinicians, yet the most modern cohort has not been evaluated. We present a systematic review over a 30-year period to examine surgical embolectomy.

Material and Methods

Literature Search Strategy

An electronic search was performed in January 2019 using Medline, Scopus, CCTR, and CINAHL to identify all relevant studies published on the use surgical embolectomy in patients with massive and submassive PE. The search was performed using the following terms: "pulmonary embolism" OR "pulmonary artery" OR "pulmonary thromboembolism" AND "embolectomy." Overall, 32 studies were selected for the analysis comprising patients with acute massive PE or submassive PE who underwent surgical embolectomy. Patient-level data were extracted for statistical analysis.

Selection Criteria

Eligible articles for the present systematic review included reports from the past 30 years that focused on surgical embolectomy for acute PE. Patients younger than 17 years of age were excluded. Reports not published in the English language, abstracts, conference presentations, editorials, reviews, registries, and expert opinions were also excluded.

Data Extraction and Critical Appraisal

Patient-level data were extracted from article texts, tables, and figures (N.D., J.W.C., M.M.). Discrepancies among the reviewers were resolved by discussion and consensus. When data were not available, attempts were made to contact the corresponding authors to obtain the relevant data for the current study.

Statistical Analysis

For dichotomous variables, a meta-analysis of proportions with logit transformation was conducted for the available main perioperative and postoperative variables. Continuous data were combined by meta-analysis with the random-effects model. Heterogeneity was evaluated using the Cochran Q and I^2 test. Egger's regression test for preoperative and postoperative systolic pulmonary artery pressure (sPAP) was performed to assess for publication bias. R software, version 3.4.2, (R Foundation for Statistical Computing, Vienna, Austria) was used for all data analysis and visualization. The meta-analysis was performed using meta package for R. P values <.05 were considered statistically significant.

Results

Study Characteristics

Overall, 3852 articles were identified in the literature search. After application of the selection criteria, a total of 32 articles, consisting of 936 patients total, were included in the analysis (Supplemental Table A). A manual search of references was performed and did not reveal any additional studies. A Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram depicting the overall search strategy is provided in the Supplemental Figure 1.

Baseline and Preoperative Characteristics

Our data demonstrated a mean patient age of 56.3 years (95% CI, 52.5, 60.1), with 50% (95% CI, 46, 55) male patients and a mean patient body mass index of 30.0 kg/m^2 (95% CI, 20.3, 39.8). Of the vital signs included on admission, results show a mean heart rate of 112 beats/min (95% CI, 98, 125), with a mean systolic blood pressure of 98 mm Hg (95% CI, 79, 116). With regard to presenting symptoms, 77% of patients presented with dyspnea (95% CI, 59, 89), 35% presented with syncope (95% CI, 18, 57), and only 23% presented with chest pain (95% CI, 16, 32). Of these presenting patients, 82% had right ventricular dysfunction on admission (95% CI, 62, 93), and 80% of these patients had unstable hemodynamics (95% CI, 67, 89). In addition, 59% of these patients were in shock (95% CI, 45, 72), and 9% of patients experienced cardiac arrest requiring cardiopulmonary resuscitation (95% CI, 5, 16). These data and additional data are shown in Table 1.

The PE was classified by the original article as massive in 83% of patients (95% CI, 43, 97) and submassive in 13% (95% CI, 2, 56). These classifications were made using the definitions listed by the author of each study at the time of publication. Earlier treatments included systemic thrombolysis for 33% of patients (95% CI, 14, 60) and catheter embolectomy for 14% of patients (95% CI, 8, 24). In addition, 32% of patients experienced a clot in transit (95% CI, 23, 42). The mean time interval from symptom onset to surgery was 6 hours (95% CI, 0, 13). Risk factors and additional preoperative data are shown in Table 2.

Preoperative Interventions and Operative Variables

Preoperatively, 10% of patients had an inferior vena cava filter (95% CI, 4, 21), 47% of patients were on a ventilator (95% CI, 26, 70), and 36% were receiving percutaneous cardiopulmonary support (PCPS) (95% CI, 11, 71). The mean operative time was 170 minutes (95% CI, 101, 239), the mean cardiopulmonary bypass time was 56 minutes (95% CI, 42, 70), and the mean intubation time was 60 hours (95% CI, 0, 124). During the operation, 50% of patients needed aortic cross-clamp (95% CI, 25, 75), and 23% of patients underwent a concomitant cardiac procedure (95% CI, 14, 36), which included PFO repair in 13% (95% CI, 9, 19), coronary artery bypass graft in 8% (95% CI, 4, 16) and mitral valve replacement or repair in 2% (95% CI, 0, 15) of patients. Overall, 93% of patients had an inferior vena cava filter inserted during the operation (95% CI, 24, 100). These data are shown in Table 3.

Surgical Outcomes and Complications

Complications are shown in Table 4. The most common complication included prolonged ventilation in 33% of patients (95% CI, 21, 47). The mean change in sPAP represented a significant decrease from the preoperative to postoperative period (preoperative sPAP, 57.8 mm Hg [95% CI, 53, 62.7]; vs postoperative sPAP, 31.3 mm Hg [95% CI, 24.9, 37.8]; $P < .01$), as shown in the forest and funnel plots of the Supplemental Figures 2A and 2B, respectively. Intraoperative mortality was 4% (95% CI 2; 8). Postoperative support included 98% of patients receiving inotropes (95% CI 8; 100), 35% of patients on a ventilator (95% CI 1; 95), and 16% on PCPS (95% CI 4; 47). These data are demonstrated in Table 4.

Survival Outcomes and Follow-up

At a mean follow-up period of 49.1 months (95% CI, 32, 66.2), the overall mortality was 22% (95% CI, 16, 29). Causes of death included heart failure or unstable hemodynamics in 15% (95% CI, 9, 26), hemorrhage in 11% (95% CI, 5, 22), multiorgan failure in 11% (95% CI, 6, 22), a neurologic cause in 9% (95% CI, 5, 14), cancer in 9% (95% CI, 5, 14), cor pulmonale or right-sided heart failure in 8% (95% CI, 4, 13), cardiac arrest in 8% (95% CI, 3, 22), and sepsis in 6% (95% CI, 2, 18). At 5 years, the overall survival was 73% (95% CI, 64, 81), and the long-term survival trend is shown in Figure 1.

The average hospital stay was 10 days (95% CI, 6, 14), with a mean intensive care unit stay of 2 days (95% CI, 1, 3) and an in-hospital mortality rate of 16% (95% CI, 12, 21). A meta-regression analysis of in-hospital mortality rate over the 30-year study time period, shown in Figure 2, suggests a trend for lower rates of in-hospital mortality for surgical embolectomies performed more recently with respect to both publication year and study midpoint year (P = .07 and P = .10, respectively). The remainder of these data are shown in Table 4.

Comment

Surgical embolectomy had once been approached as an option of last resort in a series of interventions aimed at reducing clot burden and alleviating the right ventricular overload that would lead to cardiac collapse. Our data suggest that outcomes associated with surgical embolectomy appear to have improved over the past 30 years. Given the improvements in modern cardiopulmonary bypass and surgical technique aimed at removing the PE, surgical embolectomy can be approached as a viable first-line alternative to systemic thrombolysis and anticoagulation. It may additionally be used when thrombolysis fails because mortality rates can approach 38% with repeat thrombolysis compared with lower rates for

Table 1. Baseline Characteristics of Patients With Acute Massive Pulmonary Embolism

Characteristics	Pooled Value (95% CI)	No. of Studies	No. of Patients (N or n/N)	I^2 (%)
Age (y)	56.3 (52.5, 60.1)	24	631	0
Male[a]	50 (46, 55)	35	453/876	43
BMI (kg/m^2)	30.0 (20.3, 39.8)	2	152	0
Vital signs				
Heart rate (beats/min)	112 (98, 125)	3	80	0
SBP (mm Hg)	98 (79, 116)	4	85	0
Presenting symptom				
Dyspnea[a]	77 (59, 89)	8	212/275	84
Syncope[a]	35 (18, 57)	8	55/170	82
Chest pain	23 (16, 32)	6	56/244	45
Unstable hemodynamics	80 (67, 89)	4	70/88	20
Shock[a]	59 (45, 72)	10	148/265	77
Cardiac arrest or CPR	9 (5, 16)	6	18/230	40
Vasopressors or inotropes[a]	41 (21, 66)	13	119/261	91
RV dysfunction	82 (62, 93)	13	316/410	92
Comorbidities				
Obesity[a]	44 (29, 60)	7	122/311	84
HTN	40 (31, 50)	6	39/97	0
Concurrent DVT[a]	39 (28, 52)	13	189/438	80
DM	26 (18, 37)	8	44/164	42
Hypercoagulability	11 (7, 16)	10	19/176	0
Bacterial endocarditis	11 (4, 25)	2	04/37	0
Renal failure	10 (3, 27)	3	12/63	42
History of cerebrovascular accident	10 (5, 17)	7	11/114	0
CHF	5 (1, 29)	3	8/132	82
COPD	4 (1, 13)	4	02/57	0

[a] P value for heterogeneity $<.05$.

Values are % (95% CI) unless otherwise specified.

BMI, body mass index; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease; CPR, cardiopulmonary resuscitation; DM, diabetes mellitus; DVT, deep vein thrombosis; HTN, hypertension; RV: right ventricular; SBP, systolic blood pressure.

rescue surgical embolectomy of 7%, as mentioned in a report by Meneveau and colleagues.[18] Although it is a major operation requiring median sternotomy, surgical embolectomy provides definitive treatment while reducing the risk of clot recurrence or incomplete clot removal. This complete clot removal results in rapid improvement in sPAP and prevents the circulatory collapse that could occur with incomplete clot removal or lysis. This drop in sPAP found in our data, from a preintervention value of 57.8 mm Hg to 31.3 mm Hg postoperatively, represents a significant change. Through reduction of sPAP, surgical embolectomy greatly reduces the risk of circulatory collapse because it effectively unloads the right ventricle. This reduces progression to cor pulmonale, a leading cause of death in these patients.

In an attempt to examine in-patient mortality after surgical embolectomy, a registry study of the Nationwide Inpatient Sample published by Kilic and colleagues[13] found the in-hospital mortality rate of surgical embolectomy to be as high as 27.2% in a study period from 1999 to 2008.[12,13] Alqahtani and colleagues[12] conducted a similar study but stratified their data and found that early surgical embolectomy operations, defined as the period between 2003 and 2009 in their study, had a 23.1% inpatient mortality rate, whereas later operations, defined as operations performed from 2009 to 2014, had a 14% mortality rate. Our meta-analysis found an in-hospital mortality of 16%. Therefore, our results are more in line with the latter cohort of the study by Alqahtani and colleague,[12] and suggest that outcomes may have improved over the past 10 years. Modern evaluations through single experience cohorts concur with this assessment because Pasrija and associates[19] reported an in-hospital mortality rate of 7% in a retrospective study of 55 patients. Kon and colleagues,[20] in an analysis of The Society of Thoracic Surgeons database, reported an operative mortality of 16% with respect to all patients undergoing surgical embolectomy. Other studies, by Neely and associates[21] and Keeling and colleagues,[22] seem to confirm these lower mortality rates. These results agree with our data to suggest that modern operations have better results with respect to in-patient mortality. It is possible that these noticeable improvements may stem from underlying changes to the classification of PE, although they may also reflect more aggressive approaches taken over the past 10 years.[12]

Table 2. Preoperative Characteristics

Characteristics	Pooled Value (95% CI)	No. of Studies	No. of Patients (N or n/N)	I^2 (%)
Severity of PE				
Massive	83 (43, 97)	9	217/353	97
Submassive	13 (2,56)	8	118/338	98
Prior treatment				
Prior systemic thrombolysis	33 (14, 60)	10	53/202	87
Prior catheter embolectomy	14 (8, 24)	3	11/46	0
Clot in transit[a]	32 (23, 42)	10	74/239	59
Left ventricular ejection fraction	52.7 (46.6, 58.9)	5	123	0
cTnI (ng/mL)	0.45 (0.14, 0.76)	2	82	0
sPAP (mm Hg)	57.8 (53, 62.7)	9	189	0
Diagnostic modality				
Chest CT[a]	77 (44, 94)	13	321/447	96
Echocardiogram, all[a]	87 (64, 96)	12	276/358	93
Echocardiogram, transesophageal	62 (28, 88)	4	40/68	82
Echocardiogram, transthoracic[a]	57 (20, 88)	4	59/93	89
Pulmonary angiogram	33 (7, 77)	6	55/152	94
Lung perfusion scintigraphy	4 (2, 10)	4	5/118	0
Interval from symptom to surgery (h)	6 (0, 13)	2	52	0
PE risk factor				
Recent operation	36 (29, 43)	18	151/417	47
Phlebitis or history of DVT[a]	31 (20, 44)	9	64/202	66
Immobility[a]	28 (18, 41)	15	118/373	80
Smoking[a]	24 (10, 47)	8	43/156	82
Malignancy	17 (14, 21)	24	123/682	23
Oral contraceptives	13 (4, 34)	2	3/23	0
Recent trauma	12 (8, 19)	7	17/141	0
Patent foramen ovale[a]	11 (5, 25)	5	14/110	57
Postpartum	9 (4, 18)	3	6/68	0
Pregnant or postpartum	8 (5, 14)	6	12/150	0
Fracture	8 (2, 27)	2	2/25	0
Pregnant	7 (3, 15)	3	6/82	0
Previous PE	7 (5, 11)	7	21/285	0
Major bleeding	6 (2, 13)	4	5/89	0
No PE risk factors	9 (5, 16)	6	18/230	40
IVC filter	10 (4, 21)	2	5/51	0
Percutaneous cardiopulmonary support[a]	36 (11, 71)	6	53/193	93
Ventilator[a]	47 (26, 70)	11	108/225	88

[a] *P* value for heterogeneity <.05.

Values are % (95% CI) unless otherwise specified.

CI, confidence interval; CT, computed tomography; cTnI, cardiac troponin I; DVT, deep vein thrombosis; IVC, inferior vena cava; PE, pulmonary embolism; sPAP, systolic pulmonary artery pressure.

Given that there are multiple options for the treatment of PE, including both catheter-directed therapies and surgical treatments, our analysis focused solely on surgical embolectomies for the following reasons: catheter-based studies tend to focus more on short-term outcomes, as opposed to surgical treatments; and catheter-based and surgical embolectomy patients generally have substantially different preintervention illnesses. To evaluate the long-term outcomes, we analyzed surgical embolectomy alone to understand the modern experience with respect to baseline characteristics, operative variables, and long-term outcomes yielding 30 years of experience of this technique. Given this time span, to interpret these results, a meta-regression was performed to analyze changes in in-hospital mortality over time that revealed a trend toward improving in-hospital mortality rates with respect to both publication year and study midpoint year ($P = .07$ and $P = .10$, respectively), as seen in Figure 2.

A meta-analysis by Loyalka and colleagues[23] compared catheter-based interventions with surgical embolectomy. Because the study analyzed variables present for both the

Table 3. Operative Characteristics of Patients Who Underwent Surgical Embolectomy After Acute Submassive and Massive Pulmonary Embolism

Characteristics	Pooled Value (95% CI)	No. of Studies	No. of Patients (N or n/N)	I^2 (%)
Operative time (min)	170 (101, 239)	4	128	0
CPB time (min)	56 (42, 70)	10	252	0
Intubation time (h)	60 (0, 124)	5	146	0
Aortic cross-clamp[a]	50 (25, 75)	9	109/302	92
Cardiac arrest, intraoperative	11 (7, 19)	4	12/106	0
Concomitant procedures				
All, cardiac[a]	23 (14, 36)	7	58/257	70
PFO repair	13 (9, 19)	4	27/202	0
CABG	8 (4, 16)	3	7/88	0
MV replacement or repair	2 (0, 15)	2	1/42	0
IVC filter insertion[a]	93 (24,100)	9	182/279	98

[a]Significant *P* value indicating variable heterogeneity among studies.

Values are % (95% CI) unless otherwise specified.

CABG, coronary artery bypass graft; CI, confidence interval; CPB, cardiopulmonary bypass; IVC, inferior vena cava; MV, mitral valve; PFO, patent foramen ovale.

surgical group and the catheter-based intervention group, it focused more on short-term outcomes. Further, the preintervention data for these groups were rather dissimilar. For example, the study cites patients who underwent cardiopulmonary resuscitation as 21.4% of patients in the surgical group but as only 3.9% in the catheter-based intervention group.[23] The reason for this difference, at least in part, is likely that many society guidelines, such as those of the American Heart Association the American College of Chest Physicians, and the Pulmonary Embolism Response Team Consortium, approach surgical embolectomy as salvage therapy for patients whose other treatment options have failed.[24-26] Therefore, given that the groups are not sufficiently similar, we opted not to compare these groups because one could presume a bias toward a higher mortality rate for patients undergoing surgical embolectomy. Ideally, for such a comparative study, preintervention illness would be similar among groups, but this is difficult to accomplish when surgery is approached as a final therapy rather than a viable first-line alternative, as is the case in the current climate. Additionally, as contemporary mechanical support strategies improve in outcomes and are used as a bridge to definitive treatment for profoundly ill patients with PE, the appropriate order of treatment is becoming less clear and is a topic of further study.[27]

When controlling for preintervention illness, some comparative studies have assessed surgical vs nonsurgical approaches to reach an accurate comparison. Although not including catheter-based therapy, Aymard and colleagues[28] in 2013 evaluated the differences between surgery and thrombolytic agents. They noted similar mortality rates and significantly fewer bleeding complications in surgical embolectomy when compared with thrombolytic therapy. These investigators further noted that patients with inefficient thrombolysis had worse early outcomes, a finding suggesting that earlier surgical embolectomy could provide better results than delayed surgical treatment.[28] As noted by Pasrija and associates,[19] patients with submassive PE fare better than those with massive PE with or without cardiac arrest. Other studies, such as that reported by Lehnert and associates,[29] suggest that surgical embolectomy has mortality rates similar to those with thrombolytic agents but improved pulmonary end points such as pulmonary function and 6-minute walk tests. Although these 2 studies did not include catheter-based interventions, they indicate that although short-term outcomes may be similar between thrombolytic therapy and embolectomy, long-term outcomes differ and indicate why long-term studies are important in this field. Thus, as with many nonoperative approaches, whether catheter-based therapy or using thrombolytic agents, these techniques provide less up-front risk at the expense of long-term outcomes. As the dangers of chronic thromboembolic pulmonary hypertension are becoming more apparent through reduction in 6-minute walk times and residual thrombus, we need further evaluation of long-term outcomes of all strategies to reduce clot burden in these patients.[30]

With respect to complications, our analysis noted several concerns with surgical embolectomy. Chief among these issues are respiratory complications: 22% of patients undergoing surgical treatment of PE required prolonged ventilation and had lower respiratory tract infection likely secondary to prolonged mechanical ventilation, although 47% were ventilated preoperatively. The cause of death of these patients was mostly related to congestive heart failure, hemodynamic compromise, or cor pulmonale. It is possible that these deaths are related to a delay in treatment with surgical embolectomy, although this is not directly supported by our data. Further investigation would be required to see whether time to surgical embolectomy affected these patients. The

Table 4. Survival Data and Outcomes After Surgical Embolectomy for Acute Pulmonary Embolism

Characteristics	Pooled Value (95% CI)	No. of Studies	No. of Patients (N or n/N)	I^2 (%)
Follow up period (mo)	49.1 (32, 66.2)	7	168	0
Hospital stay (ds)	10 (6, 14)	13	291	0
ICU stay (d)	2 (1, 3)	8	173	0
Overall mortality[a]	22 (16, 29)	24	119/549	67
In-hospital mortality[a]	16 (12, 21)	28	115/681	57
Intraoperative mortality	4 (2, 8)	20	41/608	68
Postoperative support				
Inotropes[a]	98 (8, 100)	2	82/90	92
Ventilator[a]	35 (1, 95)	2	18/41	89
PCPS[a]	16 (4, 47)	6	32/210	90
sPAP, postoperative (mm Hg)	31.3 (24.9, 37.8)	3	85	45
Complications				
Respiratory failure	14 (8, 23)	3	11/79	0
Tracheostomy	8 (3, 17)	3	5/64	0
Prolonged ventilation[a]	33 (21, 47)	5	82/248	73
Recurrent PE	6 (3, 13)	8	18/259	47
Pulmonary HTN	7 (2,24)	2	2/28	0
Lower respiratory tract infection	13 (6, 28)	4	10/68	31
Cardiovascular event, all	2 (0, 22)	2	1/48	35
SVT	22 (13, 36)	3	11/49	0
Congestive heart failure	5 (3, 10)	3	8/160	0
Heart failure with temporary MCS[a]	9 (1, 51)	2	17/161	90
Renal failure, all[a]	13 (7, 23)	10	56/363	74
Dialysis[a]	3 (1, 16)	4	12/253	82
Cerebrovascular event, all	4 (2, 8)	4	6/157	0
Ischemic stroke	2 (0, 16)	4	9/243	79
ICH	2 (0, 15)	2	1/42	0
Wound infection	3 (1, 7)	5	8/243	21
Sepsis	4 (2, 9)	3	9/216	0
Bleeding, all	9 (5, 15)	5	10/116	0
Reexploration	7 (4, 14)	5	8/108	0
Cause of death				
Cor pulmonale or RHF	8 (4, 13)	7	12/160	0
Severe HF or unstable hemodynamics	15 (9, 26)	3	11/71	0
Cardiogenic shock	6 (2, 15)	3	4/65	0
Cardiac arrest	8 (3, 22)	3	6/77	41
Neurologic	9 (5, 14)	8	16/184	0
Cancer	9 (5, 14)	8	15/170	0
Sepsis	6 (2, 18)	2	3/47	0
Hemorrhage	11 (5, 22)	2	6/56	0
MOF[a]	11 (6, 22)	7	21/174	53

[a] Significant *P* value indicating variable heterogeneity among studies.

Values are % (95% CI) unless otherwise specified.

CI, confidence interval; HF, heart failure; HTN, hypertension; ICH, intracerebral hemorrhage; ICU, intensive care unit; MCS, mechanical circulatory support; MOF, multiorgan failure; PCPS, percutaneous cardiopulmonary support; PE, pulmonary embolism; RHF, right-sided heart failure; sPAP, systolic pulmonary artery pressure; SVT, supraventricular tachycardia.

remainder of complications related to surgical embolectomy confirm that this procedure is not a benign intervention but indicate a mostly favorable profile.

Our analysis and other studies suggest that modern surgical embolectomy provides good survival outcomes with an acceptable complication profile. The intraoperative mortality rate continues to drop as surgical techniques improve, and in-hospital mortality has greatly improved from the 1990s, when operative mortality rates were 23% to 36%, compared with our documented 4% operative morality rate. Given this cohort of patients who present with massive and submassive PE and given that 36% present preoperatively on PCPS, these survival outcomes are surprising, especially when compared with

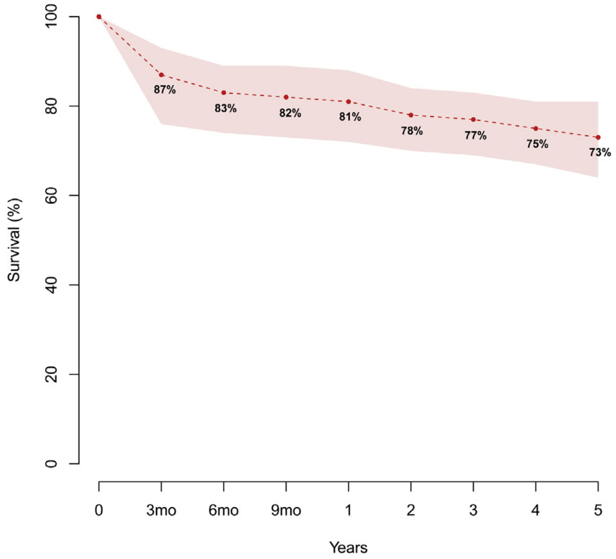

Figure 1. *Pooled-data survival analysis after surgical embolectomy for pulmonary embolism to a follow-up point of 5 years.*

early mortality rates of all presenting PE patients. Surgical embolectomy can and should be approached earlier in the treatment of massive and submassive PE because of its excellent survival rate and acceptable complication rate.

Study Limitations and Future Directions

Given the nature of a systematic review and meta-analysis, this analysis likely underestimates both complication rates and mortality rates because of reporting bias in medical literature whereby poorly performing centers are unlikely to report poor results from this intervention. As mentioned previously, our study is limited by examining only surgical embolectomy, rather than performing a comparative analysis vs catheter-based therapy. Each approach would sacrifice evaluation of certain variables and be subject to its own set of biases. We believed that by focusing solely on surgical embolectomy this study could provide greater detail with respect to perioperative variables and long-term outcomes. Although a comparative study would be ideal, as it stands, we believed that the preintervention patient groups were too different to compare and would be biased against the outcomes of surgical embolectomy, as stated previously.

Further, given that the definitions of massive and submassive PE have changed over time, we believed that using the strategy of classifying patients by the original study's reported extent would be most effective. By using more modern definitions and attempting to reclassify older reported definitions, bias could be introduced. This would potentially result in an unjustified "downgrade" of article-classified massive PE to submassive PE even if the specific parameters of the modern definition of massive PE were missing at random. Therefore, original definitions were maintained, and they may at times overestimate the percentage of massive PE.

Ideally, a prospective study that assesses surgical embolectomy as a first-line treatment with minimal delay to surgical treatment would provide an area of further investigation to determine whether surgical embolectomy is a viable alternative to systemic thrombolysis or catheter-based therapy and the complications associated with these approaches.

Conclusion

Surgical embolectomy has the potential to be a viable first-line treatment for PE, given the improvements in modern mortality rates, and it should be considered more proactively by PE care teams. Appropriate randomization of similar patients would be required to compare surgical therapy with catheter-based therapy and nonoperative approaches definitively over a period of long-term follow-up.

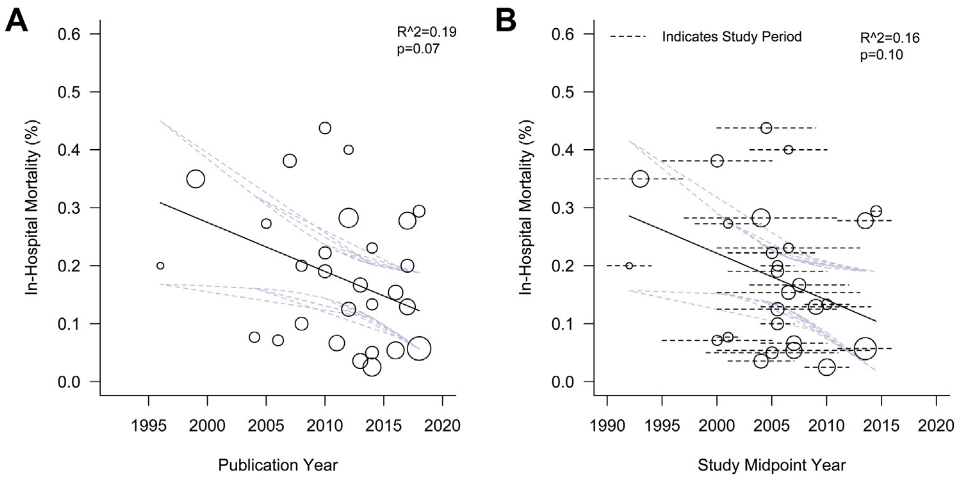

Figure 2. *(A) Meta-regression analysis of in-hospital mortality over time at publication year (B) Meta-regression analysis of in-hospital mortality over time at the midpoint of the study period, with bars indicating the total study period.*

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Is Surgical Therapy of Pulmonary Embolism Still the Last Chance?

Invited Commentary:

In this issue of *The Annals of Thoracic Surgery*, Choi and colleagues[1] present a systematic meta-analysis of the outcomes of surgical pulmonary embolectomy. Why is this such an important issue? The surgical approach is the oldest treatment of this life-threatening condition. In real life, it is often considered as the last option to save the patient's life. One reason is variable outcome data. Over the years, surgical techniques and experience have improved significantly, resulting in more favorable outcomes. The authors thoroughly investigated data from 32 studies with 936 patients over a 30-year period. Answering this question is challenging. Data of the

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