Surgical Embolectomy for Acute Pulmonary Embolism: Systematic Review and Comprehensive Meta-Analyses

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Surgical pulmonary embolectomy (SPE) is a viable treatment approach for subsets of patients with acute pulmonary embolism. However, outcomes data are limited. We sought to characterize mortality and safety outcomes for this population. Studies reporting inhospital mortality for patients undergoing SPE for acute pulmonary embolism were included. In 56 eligible studies, we found 1,579 patients who underwent 1,590 SPE operations. The pooled inhospital all-cause mortality rate was 26.3% (95% confidence interval: 22.5% to 30.5%). Surgical site complications occurred in 7.0% of operations (95% confidence interval: 4.9% to 9.8%). More investigation is required to define the patient population that would benefit the most from SPE.

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REVIEW

Acute pulmonary embolism (PE) is a disease that carries significant morbidity and mortality risk [1–4]. There is a paucity of literature describing efficacy and safety outcomes for patients undergoing surgical pulmonary embolectomy (SPE) for acute PE. The reported rates of mortality outcomes for SPE also vary widely among studies, spanning anywhere from 0% to 67% [5–9]. The current consensus guidelines from the American Heart Association and European Society of Cardiology highlight that SPE is a management option for hemodynamically unstable PE, particularly patients with absolute contraindications to thrombolytic therapy or failed systemic thrombolysis or catheter-based treatment for PE [1, 2]. Moreover, the American College of Chest Physicians recommends SPE for patients for whom shock is deemed likely to cause death before an efficacious outcome with systemic thrombolysis [3]. Other indications may include echocardiographic evidence of an embolus in transit, such as within a patent foramen ovale, right atrium, or right ventricle [10]. Consequently, there is a renewed interest in alternate treatment modalities for acute PE and, in particular, for hemodynamically unstable PE, such as catheter-based treatment and SPE [9].

Despite the consensus guidelines, SPE has historically been limited to large centers owing to the need for institutional surgical expertise, requirement for cardiopulmonary bypass, and availability of extracorporeal membrane oxygenation (ECMO), as well as heterogeneity in reported outcomes data on efficacy and safety of SPE [5, 11–19]. In addition, the emergence of new therapies such as catheter-based therapy and the availability of ECMO have made the clinical role of SPE less clear in clinical practice.

Given the interest in SPE and its uncertain place in contemporary PE treatment algorithms, we conducted the current investigation to provide estimates of mortality, efficacy, and safety outcomes of patients who have undergone SPE for acute PE.

Material and Methods

Search Strategy

We searched the SCOPUS database from 1945 until June 2015 for eligible studies, with a predefined list of terms. SCOPUS comprises Medline and a number of other databases, including Embase, Compendex, World Textile Index, Fluidex, Geobase, and Biobase [20]. (The study protocol is detailed in Supplemental Material, Section 1.)

The Supplemental Materials can be viewed in the online version of this article [http://dx.doi.org/10.1016/j.athoracsur.2016.11.016] on http://www.annalsthoracicsurgery.org.

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Study Characteristics

All English language observational studies involving five or more patients that reported mortality outcomes after SPE were included. When groups reported cumulative or longitudinal results in more than one publication, we included only studies with the largest sample size and the most comprehensive follow-up period for each outcome (Fig 1).

Outcome Measures

Our primary outcome was inhospital mortality rate per 100 patients undergoing SPE. Secondary outcomes included inhospital cardiovascular (CV) and non-CV mortality rates and long-term all-cause, CV, and non-CV mortality rates. Safety outcomes were divided into surgical site complications (including surgical site bleeding, reoperation for bleeding, wound dehiscence, or mediastinitis), incidence of pulmonary bleeding, incidence of gastrointestinal bleeding, and incidence of bleeding at nonsurgical sites. (Detailed definitions for these outcomes are presented in Supplemental Table 1.)

Data Extraction

All titles and abstracts were searched by two authors (R.K. and M.I.A). All relevant full-text manuscripts were then retrieved and screened on the basis of inclusion criteria and study outcomes. We then assessed methodologic quality using the Newcastle-Ottawa scale. Two authors (P.A. and N.S.B.) randomly checked all data collection for consistency. The authors resolved all disagreements through unanimous consensus.

Data Synthesis and Statistical Analyses

We conducted statistical analyses using Comprehensive Meta-Analysis, version 2 (Biostat, Englewood, NJ), and STATA, version 14.0 (StataCorp, College Station, TX). We used random effects modeling for estimating pooled rates of efficacy and safety outcomes because of the observational nature of the data. Studies with zero events were handled as described by Bradburn and colleagues [21]. Publication bias for the primary outcome was assessed using the Funnel plot and Egger's regression method [22]. A one-tailed p value less than 0.05 was considered significant. Corrected estimates were calculated using the Duval and Tweedie trim and fill method if there was significant publication bias [23]. Meta-regression analyses were performed utilizing the method of moments to explore heterogeneity in study primary efficacy outcome [24]. All p values were two-tailed, except as described, with statistical significance defined at p less than 0.05, and confidence interval (CI) computed at the 95% level. The analysis has been reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [25].

Results

Our literature search yielded 56 studies involving 1,579 patients who underwent 1,590 SPE operations [6–8, 13, 16, 26–76]. Supplemental Table 8 details the PRISMA checklist. Baseline characteristics of all studies are presented in Table 1. The mean and median age of the patients ranged from 42 to 62 years. The incidence of preoperative cardiac arrest was reported in 45 studies with 1,402 patients and occurred in 33.9% of operations (95% CI: 28.5% to 39.8%). Of 56 studies, 18 studies with 621 patients reported data on the use of preoperative ECMO. Among these studies, the usage of preoperative ECMO was reported in 18 studies with 621 patients, with ECMO being

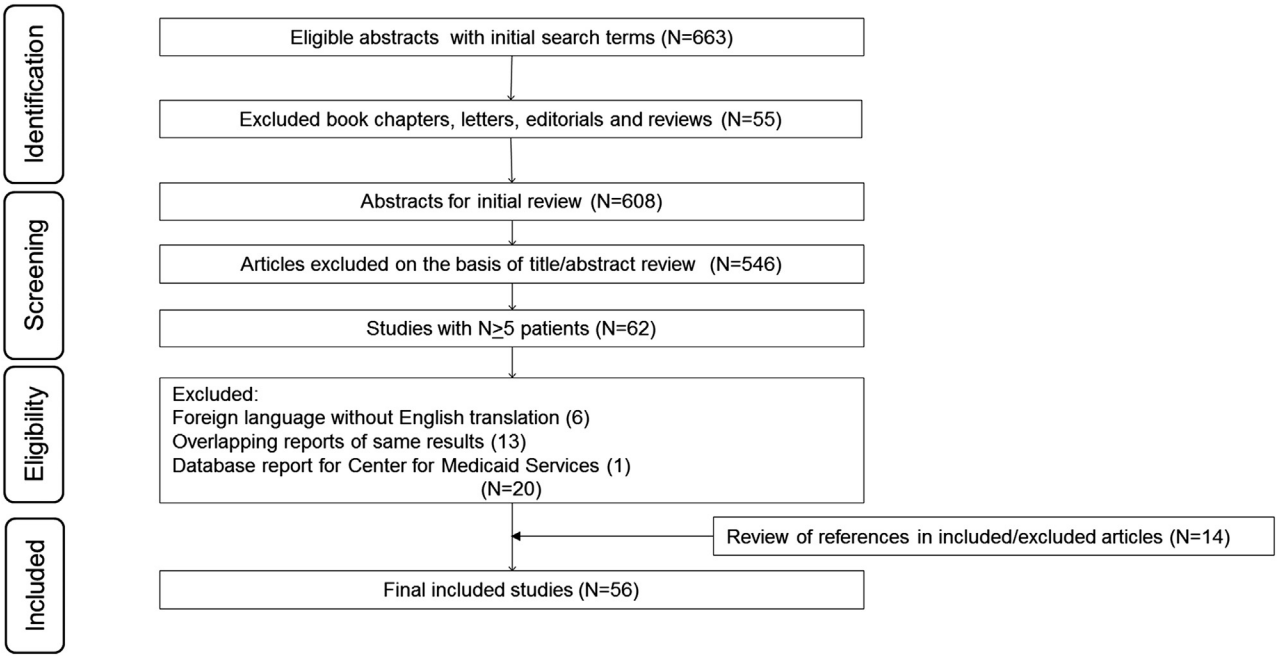

Fig 1. Flow diagram for study selection.

Table 1. Baseline Characteristics of Included Studies

First Author, Year [6–8, 13, 16, 23–76]	Patients/ Operations (n)	Age, Years (mean or median, range or SD)	Follow-Up (person-years)	Male (%)	Systemic Thrombolytics Contraindication (%)	Preoperative Cardiac Arrest (%)	RV Dysfunction (%)	Need for Inotropes or Vasopressors (%)	Preoperative Mechanical Ventilation, CPB, or ECC (%)	Preoperative Systemic Thrombolysis (%)
Vossschulte, 1965	7/7	48.7 (4.3)	NR	57.1	NR	14.3	NR	NR	NR	NR
Berger, 1973	17/17	NR	NR	52.9	NR	NR	NR	NR	NR	NR
Turnier, 1973	8/8	56.8 (13.4)	NR	50.0	NR	50.0	NR	NR	NR	NR
Hennig, 1974	6/6	NR	10.0	NR	NR	NR	NR	NR	NR	NR
Rivas, 1975	5/5	NR	NR	NR	NR	NR	NR	NR	NR	NR
De Weese/1976	11/11	42.3 (14.5)	NR	45.5	NR	NR	45.5	NR	45.5	NR
Saylam, 1978	8/8	58.5 (9.6)	NR	62.5	NR	12.5	NR	100.0	12.5	NR
Satter, 1980	36/36	NR	NR	44.4	100.0	NR	NR	NR	NR	NR
Bottzauw, 1981	23/23	53 (17)	NR	56.5	30.4	69.6	52.2	NR	NR	0.0
Estrera, 1981	5/5	43.6 (17.5)	NR	60.0	NR	60.0	NR	80.0	NR	NR
Glassford, 1981	20/20	57.1 (14.8)	NR	40.0	NR	50.0	NR	NR	NR	NR
Mattox, 1982	39/40	42	NR	25.6	NR	87.2	NR	NR	87.2	NR
Clarke, 1986	55/57	(16–72)	NR	45.5	NR	34.5	NR	NR	NR	NR
Jaumin, 1986	23/23	NR	NR	NR	NR	NR	NR	NR	NR	NR
Lund, 1986	25/25	52 (16–71)	97.5	56.0	NR	28.0	44.0	NR	NR	NR
Stalpaert, 1986	30/30	44.5	NR	30.0	NR	NR	NR	NR	NR	NR
Gray, 1988	71/71	43.1 (15–75)	559.7	31.0	29.6	39.4	NR	NR	NR	2.8
Bauer, 1991	44/44	49 (15)	202.4	54.5	15.9	34.1	NR	29.5	NR	NR
Biglioli, 1991	11/11	NR	NR	NR	NR	NR	NR	NR	NR	54.5
Boulafendis, 1991	16/16	51.5 (19–73)	80.7	62.5	NR	31.3	NR	100.0	100.0	0.0
Kieny, 1991	134/134	55 (23–78)	NR	55.2	NR	17.2	NR	26.1	NR	17.2
Meyer, 1991	96/96	52 (19–77)	448.0	52.1	10.4	25.0	88.5	81.3	NR	31.3
Khoury, 1992	61/61	53 (5)	NR	32.8	NR	27.9	NR	63.9	NR	11.5
Meyns, 1992	30/30	47.8 (15)	217.5	33.3	NR	40.0	NR	NR	NR	3.3
Laas, 1993	34/34	(21–79)	166.6	NR	NR	NR	NR	NR	NR	NR
Stulz, 1994	50/54	53.4 (14–77)	NR	36.0	NR	62.0	NR	96.0	2.0	2.0
Jakob, 1995	25/25	57 (25–78)	NR	40.0	NR	NR	NR	NR	NR	24.0
Doerge, 1998	41/41	51.1 (16–75)	433.9	51.2	9.8	34.1	NR	80.5	58.5	14.6
Ullman, 1999	40/40	55 (17)	150.0	42.5	NR	37.5	NR	32.5	NR	NR
Caleb, 2002	12/12	(34–76)	NR	41.7	25.0	41.7	NR	100.0	NR	NR
Yalamanchili, 2004	13/13	53.7 (10.9)	NR	46.2	NR	15.4	100.0	30.8	46.2	NR
Dauphine, 2005	11/11	48.5 (9.5)	8.3	45.5	45.5	36.4	NR	36.4	NR	27.3
Leacche, 2005	47/47	59 (14)	105.8	63.8	44.7	12.8	95.2	NR	NR	8.5
Spagnolo, 2006	21/21	(35–75)	NR	38.1	NR	23.8	100.0	90.5	NR	NR
Amirghofran, 2007	11/11	45.6 (33–72)	33.0	63.6	NR	27.3	NR	NR	NR	NR

(*Continued*)

Table 1. Continued

First Author, Year [6–8, 13, 16, 23–76]	Patients/ Operations (n)	Age, Years (mean or median, range or SD)	Follow-Up (person-years)	Male (%)	Systemic Thrombolytics Contraindication (%)	Preoperative Cardiac Arrest (%)	RV Dysfunction (%)	Need for Inotropes or Vasopressors (%)	Preoperative Mechanical Ventilation, CPB, or ECC (%)	Preoperative Systemic Thrombolysis (%)
Digonnet, 2007	21/21	62 (12.5)	99.8	61.9	4.8	28.6	100.0	NR	4.8	NR
Konstantinov, 2007	7/7	46.4 (16.1)	29.2	28.6	NR	85.7	28.6	NR	14.3	0.0
Sa, 2007	12/12	46 (17)	102.0	58.3	33.3	NR	66.7	NR	NR	58.3
Ahmed, 2008	15/15	59.6 (35–89)	NR	46.7	20.0	NR	80.0	40.0	53.3	26.7
Gan, 2008	9/9	NR	NR	NR	NR	NR	NR	NR	NR	NR
Barrett, 2010	9/9	62	NR	55.6	100.0	44.4	NR	NR	NR	0.0
Sareyyupoglu, 2010	18/18	60 (28–78)	24.0	72.2	72.2	38.9	72.2	50.0	50.0	NR
Vohra, 2010	21/21	55 (24–70)	66.5	71.4	47.6	42.9	100.0	66.7	NR	52.4
Greelish, 2011	15/15	57 (25–90)	30.0	86.7	26.7	13.3	100.0	NR	6.7	NR
Lehnert, 2012	33/33	55 (19–77)	171.6	51.5	39.4	3.0	97.0	42.4	18.2	18.2
Malekan, 2012	26/26	59.1 (23–82)	2.2	69.2	NR	NR	73.1	7.7	3.8	NR
Marshall, 2012	10/10	49 (25–72)	32.5	40.0	100.0	60.0	100.0	NR	NR	0.0
Takahashi, 2012	24/25	59.9 (17.2)	13.6	29.2	16.7	45.8	100.0	NR	66.7	12.5
Taniguchi, 2012	32/32	57 (18–82)	2.7	34.4	NR	9.4	9.4	NR	31.3	25.0
Thielmann, 2012	46/46	50.5 (15.3)	3.8	32.6	NR	26.1	82.6	63.0	65.2	15.2
Salehi, 2013	16/16	53 (17.8)	32.0	37.5	NR	NR	90.0	18.8	NR	NR
Wu, 2013	25/25	49.4 (18.7)	39.6	36.0	96.0	32.0	96.0	NR	NR	4.0
Zarrabi, 2013	30/30	58.2 (15.6)	76.3	50.0	23.3	10.0	NR	NR	NR	33.3
Osborne, 2014	15/16	48.5 (17.7)	1.3	46.7	NR	6.7	73.3	NR	NR	NR
Yavuz, 2014	13/13	61.8 (14.0)	27.1	61.5	NR	30.8	100.0	100.0	30.8	0.0
Hartman, 2015	96/98	57.7 (14.5)	240.0	62.5	NR	0.0	100.0	25.0	NR	5.2

CPB = cardiopulmonary bypass; ECC = extracorporeal circulation; n = number; NR = not reported; RV = right ventricular.

instituted in 27.2% of operations (95% CI: 17.8% to 39.3%). Contraindications to preoperative systemic thrombolysis were reported by 21 studies and existed in 36.0% of patients (95% CI: 25.5% to 48.0%) in these studies. There was marked variation in the use of preoperative systemic thrombolysis and perioperative inferior vena cava filter implantation. There were also wide variations in surgical technique and perioperative care, as noted in Table 1. Although use of cardiopulmonary bypass appeared to be nearly universal, there was no clear consensus on the use of intraoperative hypothermia, cardioplegic arrest, or use of a beating-heart procedure on cardiopulmonary bypass. Quality assessment of all studies was undertaken according to the Newcastle-Ottawa criteria, as outlined in Supplemental Table 2. Procedural characteristics are reported in Supplemental Table 3.

Efficacy Outcomes

The outcomes reported by individual studies are reported in Supplemental Table 4. Point estimates for inhospital and long-term mortality outcomes are reported in Table 2. In-hospital mortality point estimates for each study are detailed in Supplemental Table 9.

Inhospital all-cause mortality was reported by all 56 studies involving 1,579 patients. The inhospital mortality rate was estimated to be 26.3% (95% CI: 22.5% to 30.5%; Fig 2). The inhospital CV mortality rate was reported in 45 studies and was estimated to be 14.2% (95% CI: 11.2% to 17.8%). The inhospital non-CV mortality rate was reported in 45 studies and was estimated to be 14.8% (95% CI: 12.0% to 18.1%). Long-term all-cause mortality was reported in 31 of 56 studies with a total follow-up of 3,508 person-years. The long-term all-cause mortality rate was estimated to be 6.5 per 100 person-years (95% CI: 4.9 to 8.1). The long-term CV and non-CV mortality rates were reported in 27 studies over 3,215 person-years. The long-term CV and non-CV mortality rates were 1.7 per 100 person-years (95% CI: 1.0 to 2.3) and 3.8 per 100 person-years (95% CI: 2.7 to 4.8), respectively.

Safety Outcomes

The safety outcomes are not well reported by individual studies (Supplemental Table 4). Point estimates for surgical site complications (which also includes surgical site bleeding), gastrointestinal bleeding, pulmonary bleeding, and non–surgical site bleeding are reported in Table 3. Surgical site complications were reported in 17 studies with 615 operations. The estimated incidence was 7.0% of operations (95% CI: 4.9% to 9.8%). Gastrointestinal bleeding was reported by 10 studies with 421 operations, and the incidence was estimated to be 3.0% of operations (95% CI: 1.7% to 5.2%). Pulmonary bleeding was reported by 10 studies with 283 operations, and the incidence was estimated to be 4.0% of operations (95% CI: 2.1% to 7.3%). Other bleeding at nonsurgical sites was reported by 13 studies with 461 operations, and the incidence was estimated to be 10.6% of operations (95% CI: 5.3% to 19.8%).

Sensitivity and Subgroup Analyses

We observed substantial heterogeneity in the inhospital all-cause mortality rate with an I^2 statistic of 59.6%. To explore the reasons for this heterogeneity among rates of inhospital mortality, we performed subgroup analysis by time and explored the role of preoperative cardiac arrest on inhospital mortality by meta-regression. We performed a subgroup analysis by stratifying studies published before and after the year 2000. That was notable for showing a marked difference among inhospital mortality in those subgroups ($p < 0.001$; Supplemental Table 5). That likely indicates significant changes in perioperative care and the management of PE. We also attempted to evaluate the differences in inhospital mortality between centers performing high volumes of SPE and those performing fewer procedures. To evaluate this, we compared inhospital mortality between centers reporting outcomes for 20 or more patients undergoing SPE with centers reporting outcomes for fewer than 20 patients. There was a positive but nonsignificant trend when comparing mortality between these types of centers in our subgroup analysis ($p = 0.17$; Supplemental Table 6). In view of these data, we attempted to combine the subgroup analyses to determine the effect of procedural volume in the contemporary area. Among studies published after the year 2000, we found that there was a statistically significant difference in inhospital mortality between centers reporting outcomes on 20 or more patients undergoing

Table 2. Mortality Outcomes of Patients Undergoing Surgical Pulmonary Embolectomy for Pulmonary Embolism

Variables	Studies (n)	Patients (n)	Events (n)	Point Estimate (CI)	Heterogeneity Measures
Inhospital data					
All-cause mortality	56	1,579	395	26.3% (22.5%–30.5%)	$I^2 = 59.6\%$ ($p < 0.001$)
CV mortality	45	1,282	167	14.2% (11.2%–17.8%)	$I^2 = 50.4\%$ ($p < 0.001$)
Non-CV mortality	45	1,282	173	14.8% (12.0%–18.1%)	$I^2 = 40.6\%$ ($p = 0.003$)
Long-term follow-up data					
All-cause mortality	31	3,508[a]	246	6.5 (4.9–8.1)[b]	$I^2 = 64.1\%$ ($p < 0.001$)
CV mortality	27	3,215[a]	80	1.7 (1.0–2.3)[b]	$I^2 = 34.3\%$ ($p = 0.043$)
Non-CV mortality	27	3,215[a]	146	3.8 (2.7–4.8)[b]	$I^2 = 43.9\%$ ($p = 0.008$)

[a] Follow-up in person-years. [b] Point estimate per 100 person-years.

CI = confidence interval; CV = cardiovascular; n = number.

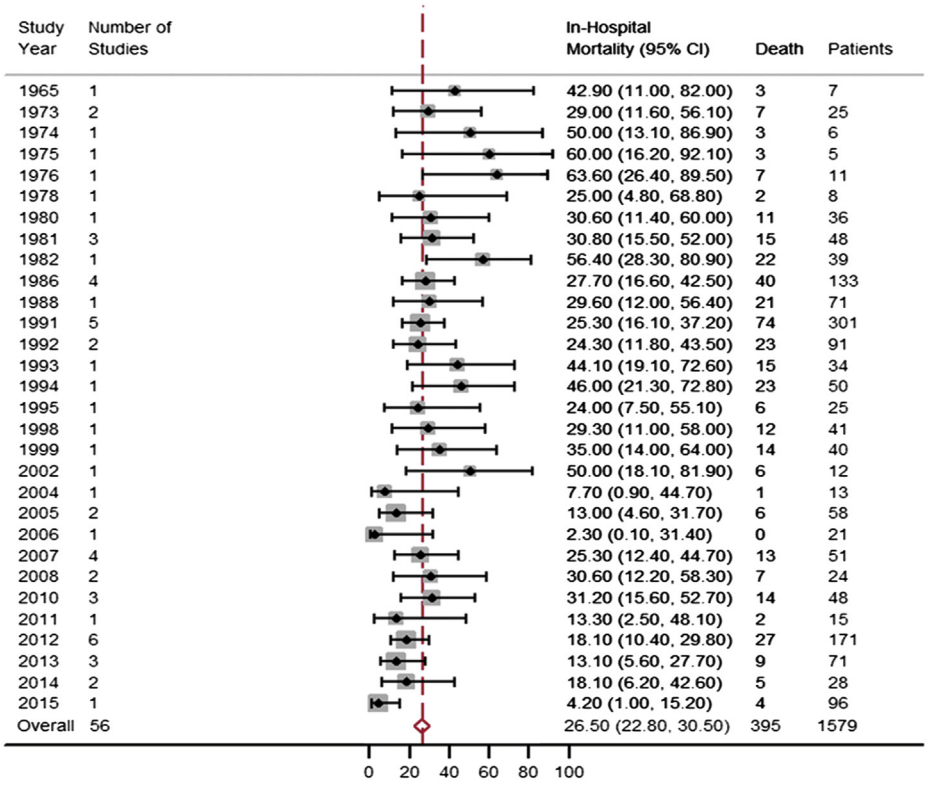

Fig 2. Forest plot depicting inhospital mortality rates (per 100 patients) undergoing surgical pulmonary embolectomy for acute pulmonary embolism. Each black diamond is the point estimate, the line represents the 95% confidence interval (CI). The gray box represents the weight of the studies. The hollow red diamond and dashed red line represent the random effects generated overall estimate.

SPE compared with centers reporting fewer than 20 patients' outcomes ($p = 0.016$; Supplemental Table 7).

Meta-regression analysis revealed that studies with a higher proportion of patients with preoperative cardiac arrest had a significantly higher logit inhospital mortality rate ($\beta = 0.025$, $p < 0.001$; Fig 3). We also performed meta-regression analyses to evaluate the impact of preoperative ECMO usage and preoperative systemic thrombolysis usage on logit inhospital mortality rate. We were unable to find statistically significant trends between the usage of these modalities and logit inhospital mortality rate ($\beta = 0.007$, $p = 0.41$, and $\beta = -0.01$, $p = 0.29$, respectively; Supplemental Figs 1 and 2, respectively).

Publication Bias

We observed publication bias using Egger's regression method ($p = 0.005$) but corrected estimates for inhospital mortality using trim and fill did not differ from random effects estimates. The results of this are outlined in Supplemental Figure 3.

Comment

Our systematic review and meta-analyses examined mortality and safety outcomes in 56 studies involving 1,579 patients who underwent 1,590 SPE operations. The analyses yielded an inhospital all-cause mortality estimate of 26.3% and a long-term all-cause mortality rate of 6.5 deaths per 100 person-years. Among these patients, a third had cardiac arrest before being taken to surgery, and among reported studies, nearly a third of operations required institution of preoperative ECMO support. The incidences of surgical site complications, gastrointestinal bleeding, pulmonary bleeding, and other bleeding at nonsurgical sites were 7.0%, 3.0%, 4.0%, and 10.6% of operations, respectively.

Table 3. Safety Outcomes of Surgical Pulmonary Embolectomy for Pulmonary Embolism

Complications	Studies (n)	Operations (n)	Events (n)	Point Estimate per 100 Operations (CI)	Heterogeneity Measures
Gastrointestinal bleeding	10	421	10	3.0 (1.7–5.2)	$I^2 = 0.0\%$ ($p = 0.989$)
Pulmonary bleeding	10	283	8	4.0 (2.1–7.3)	$I^2 = 0.0\%$ ($p = 0.942$)
Other bleeding	13	461	36	10.6 (5.3–19.8)	$I^2 = 71.0\%$ ($p < 0.001$)
Surgical site complications	17	615	35	7.0 (4.9–9.8)	$I^2 = 10.1\%$ ($p = 0.336$)

CI = confidence interval; n = number.

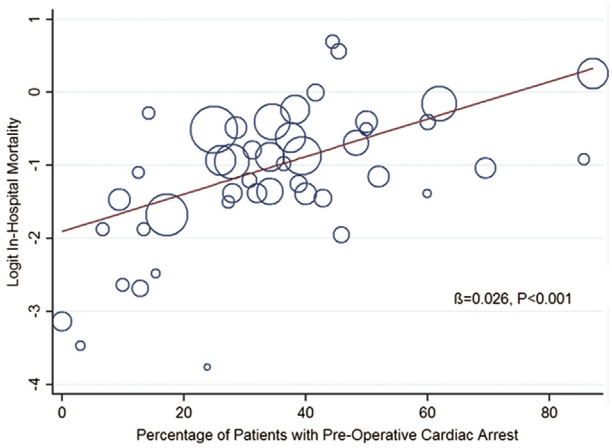

Fig 3. Meta-regression of preoperative cardiac arrest on logit inhospital mortality rate. The size of the blue circles represents the weight of the study. The red line is fitted using the method of moments.

The results of our analyses can be explained through several key mechanisms. The most reasonable physiologic explanation of the efficacy of SPE for acute PE is that surgical relief of a large thromboembolic obstruction rapidly reduces right ventricular (RV) strain and reverses the ventriculoarterial uncoupling [2]. That likely reduces the risk of progression to cardiogenic shock and leads to reduced inhospital mortality.

There are several key findings that our data highlight when compared with the available literature. The observation that preoperative cardiac arrest predicts mortality from SPE has been highlighted numerous times in the past [11, 38, 56, 57, 77]. We also observed a trend toward higher inhospital mortality among patients with preoperative cardiac arrest. This observation again implies that for high-risk patients, SPE should be considered for patients before the development of advanced hemodynamic instability, and certainly before progression to cardiogenic shock. It is also of great interest to us that the long-term CV and non-CV mortality rates are similar in our analyses. This finding supports the observation that PE may often be a disease of comorbidity, and a patient's death will often be due to the underlying predisposing disease rather than the PE itself if the PE is adequately treated. Hence, this observation also suggests that early amelioration of hemodynamic compromise may lead to reasonable long-term outcomes. Consequently, we attempted to elucidate the relationship between preoperative ECMO and systemic thrombolytic usage on inhospital mortality (Supplemental Figs 1 and 2), but were unable to find one. We caution readers, however, in drawing any firm conclusions about these modalities on the basis of these sensitivity analyses, as the current literature base is limited by incomplete reporting and reporting bias. We look forward to future series exploring these relationships.

Our data reinforce earlier suggestions that inhospital mortality rates have dropped over time for patients undergoing SPE for PE, particularly at centers where surgeons are performing greater volume of SPE (Supplemental Tables 5 and 7) [9]. That likely reflects improved patient risk stratification, more rapid and accurate diagnostic modalities and protocols, and significant advancements in perioperative care. Based on the significant medical, perioperative, and critical care expertise required for SPE procedures, we acknowledge that having a diverse multidisciplinary surgical and critical care program is the key and that such procedures are ideally done at centers with dedicated programs.

Our analysis has therapeutic implications. The increasing availability of ECMO and efforts to standardize the surgery for SPE, such as that made by the European Society of Cardiology consensus guidelines, suggest that SPE has a place in the treatment of PE with severe RV dysfunction or hemodynamic instability [2]. In conjunction with our analysis, that highlights a very discernible need to reeducate both medical and surgical trainees regarding the role of SPE in the treatment of acute PE [5]. Moreover, the trend toward improving mortality estimates noted in our analysis suggests the need to reevaluate the prevailing view that hemodynamic instability and cardiac arrest should be the only indications for SPE. These favorable estimates lend support to the use of SPE as an effective treatment option for PE with severe RV dysfunction and hemodynamic instability, particularly at centers where surgical expertise in performing SPE is available. A number of groups have adopted protocols to include hemodynamically stable patients with RV dysfunction, and that has appeared to improve morbidity and mortality outcomes for PE [16, 56]. Compared with those groups, however, our analysis may be a more accurate reflection of current practice as more than one third of our included population had cardiac arrest before SPE. Nonetheless, our data support the inclusion of patients before hemodynamic instability. We also suggest that arbitrary cutoffs (such as systolic blood pressure less than 90 mm Hg) should not be the sole determinant in deciding operative candidacy for this devastating disease—clinician judgment should again prevail to highlight those patients in the tenuous clinical state bordering on hemodynamic instability and collapse. Additional research should also be aimed at identifying how to stratify severity for this so-called "high risk but hemodynamically stable" patient group.

We recognize that our analyses also have limitations. Amalgamation of aggregate patient data in meta-analyses has well-known limitations [78]. Published studies on SPE frequently exhibit a discernible lack of data on comorbidities, hemodynamic data, echocardiographic and radiographic data, as well as data on the institution of ECMO among these patients. That lack is likely due to a combination of the acuity of the PE being treated and an evolution in the understanding of the hemodynamic outcomes and definitions of PE since the publication of initial case series. Therefore, we are able to assess only the role of preoperative cardiac arrest and the impact of improved protocols over time. There is a clear need for more prospective data in these areas. In addition, there is

a need to evaluate long-term outcomes, particularly the rate of development of chronic thromboembolic pulmonary hypertension, of patients who undergo SPE for acute PE. Finally, we note that there is variation in the indications for SPE in our patient populations. Although not all patients technically exhibited hemodynamic instability using the cutoffs specified in consensus guidelines [1–3], it is clearly justifiable to assume that there was heightened clinical suspicion for significant PE that led treating clinicians to pursue SPE. Consequently, we strongly believe that all of these patients be considered high risk, as SPE was traditionally a recourse reserved only for patients who were in extremis. As a corollary, this concept again underlines the difficulty of classifying the disease spectrum of PE in an artificial and categoric fashion.

In conclusion, surgical pulmonary embolectomy is an effective treatment option for acute PE with high-risk features. Our analyses note favorable mortality estimates with a trend toward improvement in modern series. Further research is needed to define the place of SPE in the treatment of PE.

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