Surgical Pulmonary Embolectomy

Timothy J. Poterucha, MD; Brian Bergmark, MD; Sary Aranki, MD; Tsuyoshi Kaneko, MD; Gregory Piazza, MD, MS

Case Presentation
A 66-year-old man with a recent prosthetic knee infection, status post-prosthesis removal, was admitted with recurrent septic arthritis. On his seventh hospital day, as he was signing his discharge paperwork, he developed acute respiratory distress. On physical examination, he was tachycardic to 118 beats/min, relatively hypotensive from 144/78 mm Hg earlier in the day to 94/54 mm Hg, and hypoxic, with an oxygen saturation of 94% on a 100% nonrebreather facemask. The ECG showed sinus tachycardia. An urgent contrast-enhanced chest computed tomogram (CT) demonstrated large saddle pulmonary embolism (PE) and severe right ventricular (RV) enlargement, with an RV diameter-to-left ventricular (LV) diameter ratio of 1.8 (Figure 1). The patient was administered a bolus of intravenous unfractionated heparin followed by a continuous infusion. An urgent bedside transthoracic echocardiogram showed severe RV dilation, moderate-to-severe pulmonary hypertension, and RV pressure overload as suggested by systolic deviation of the interventricular septum toward the LV (Figure 2). The Vascular Medicine and Cardiac Surgery services were consulted for consideration of advanced therapies. Because of concern for major bleeding associated with fibrinolytic therapy in the setting of recent major surgery, surgical pulmonary embolectomy was recommended.

Introduction
Despite advances in diagnostics and therapeutics, acute PE remains a life-threatening condition with an in-hospital mortality rate of ≈7% for all-comers and 31% for patients with hemodynamically unstable (massive) PE.1 Current management algorithms emphasize risk stratification to identify patients who may benefit from early advanced therapies in addition to anticoagulation.2–4 Risk categories of massive, submassive, and low-risk PE are based on clinical, radiological, and laboratory criteria. Massive PE is characterized by systemic arterial hypotension, syncope, cardiogenic shock, cardiac arrest, or respiratory failure. Submassive PE is defined by evidence of RV dysfunction on imaging (RV/LV diameter >0.9 on contrast-enhanced chest CT or RV dilation and hypokinesis on echocardiography), elevated cardiac biomarkers (such as cardiac troponin), or both, in a patient with preserved systemic arterial pressure. Submassive PE comprises a patient population at increased risk of adverse outcomes and early mortality. Low-risk PE patients have none of these features and typically have an uneventful clinical course when treated with therapeutic anticoagulation alone.

Advanced therapies are often considered for patients with submassive or massive PE to rapidly relieve RV pressure overload and avert hemodynamic deterioration. Advanced therapies for reperfusion include systemic fibrinolysis, catheter-based pharmacomechanical intervention, and surgical pulmonary embolectomy. A recent meta-analysis showed a 1.7% absolute mortality...
benefit with systemic fibrinolysis versus anticoagulation alone in submassive PE, but this was achieved with the cost of a 6% absolute increase in the rate of major bleeding, including a 1.5% rate of intracranial hemorrhage. The intracranial hemorrhage rate with systemic fibrinolysis has been estimated to be 3% in the real-world experience of the International Cooperative Pulmonary Embolectomy Registry, which included all patients with acute PE.

Fear of the risk of intracranial hemorrhage associated with systemic fibrinolysis has driven strong interest in alternative therapies to rapidly relieve RV pressure overload, while minimizing the risk of intracranial hemorrhage. Although catheter-based pharmacomechanical therapy is emerging as a promising strategy, surgical pulmonary embolectomy has been available for several decades as an option for the ≈40% of patients with PE who have at least 1 contraindication to systemic fibrinolysis. As surgical techniques, experience, and perioperative care have improved, the potential to expand the role of surgical pulmonary embolectomy has grown.

### Historical Use of Surgical Pulmonary Embolectomy

The first successful surgical pulmonary embolectomy was performed in Germany in 1924 by Dr Martin Kirschner, and cardiopulmonary bypass was incorporated when it became available in the 1960s. Surgical mortality rates in the middle-to-late 20th century exceeded 30%, resulting in the restriction of surgical pulmonary embolectomy to patients in refractory shock with no other options. The observation that surgical pulmonary embolectomy was rarely associated with favorable outcomes led to the conclusion that patients who died during the operation were too ill to undergo surgery, whereas those who survived surgery were well enough that they should have been managed medically. As a result, the operation was doomed to failure, with patients being considered too sick or too well to undergo surgical pulmonary embolectomy. The technique was abandoned at most hospitals in the 1980s to 1990s.

During this time, surgical techniques were refined in a small number of centers and outcomes began to improve. A study by Galba et al showed a 77% survival rate with surgical pulmonary embolectomy in patients with shock from PE, which was comparable to the 67% survival rate demonstrated with fibrinolytic therapy. In a cohort of 24 patients with circulatory collapse, including nearly half who were resuscitated from a cardiac arrest, Takahashi et al reported a 5-year survival rate of 87.5%. In addition, this cohort had excellent long-term recovery, with estimated pulmonary artery systolic pressures decreasing from a mean of 66.9 to 28.5 mm Hg. The evidence for favorable outcomes with surgical pulmonary embolectomy in massive PE has led to an increase in the use of surgical pulmonary embolectomy as first-line treatment rather than as rescue therapy.

### Surgical Pulmonary Embolectomy in Submassive PE

With the encouraging outcomes data for surgical pulmonary embolectomy in the treatment of massive PE, some experts have advocated that surgical pulmonary embolectomy could be a valid option for patients with submassive PE at high risk for adverse outcomes or with contraindications to fibrinolysis. In 2002, Aklog et al published their results of surgical pulmonary embolectomy in a series of 29 patients with submassive PE, with evidence of moderate-to-severe RV dysfunction, showing an 89% 1-month survival. Notably, this was a single-center study with a dedicated team of a single cardiologist and 2 cardiothoracic surgeons available 24 hours a day, and the surgery was performed without the use of cardioplegia or aortic cross-clamping. The first patients treated in this cohort had a high rate of recurrent PE, resulting in life-threatening decompensation, and inferior vena cava (IVC) filter placement was...
associated with reduced PE recurrence and improved outcomes. A subsequent report from the same center in 2005 with 47 patients showed a 6% operative mortality and 86% 1-year survival.14

Greelish et al15 reported a case series in 2011 of 107 patients with central PE in which 15 patients were treated surgically and 88 medically. In this cohort, 47% of patients treated with surgery had hypotension on presentation in comparison with 8% in the medical management group. Despite the higher acuity among the patients in the surgical group, their survival was improved, with 29% of patients in the surgical arm and 43% of patients in the medical management arm dying within the first 30 days. Both deaths in the surgical group occurred in patients requiring preoperative cardiopulmonary resuscitation. Similar to the experience of Aklog et al,13 nearly all patients in the surgical arm had IVC filters placed perioperatively.

The largest case series of surgical embolectomy by Neely et al16 shows that outcomes for surgical pulmonary embolectomy have continued to improve. In a series of 115 patients undergoing surgical pulmonary embolectomy, the authors report an overall mortality rate of 6.6%. Notably, this study included 56 patients with submassive PE who underwent surgical pulmonary embolectomy because of contraindications to fibrinolysis, failure of catheter-based therapies, or severe RV dysfunction. In the subgroup of patients with submassive PE, the operative mortality rate was 3.6%.

Recent registry data have suggested improved survival for patients with massive PE who proceed directly to surgical pulmonary embolectomy, rather than reserving surgical pulmonary embolectomy for those in whom fibrinolysis is unsuccessful.17 With short-term surgical mortality rates ranging from 3.6% to 13% in the most recent studies,12–17 the potential of first-line surgical pulmonary embolectomy as an alternative to systemic fibrinolysis has expanded.

**Indications for Surgical Pulmonary Embolectomy**

The American Heart Association, American College of Chest Physicians, and European Society of Cardiology recommend surgical pulmonary embolectomy for patients with massive PE and contraindications to fibrinolysis who have surgically accessible, centrally located PE (Table 1).2–4

Contraindications for systemic fibrinolysis include active bleeding, recent ischemic stroke, any past history of...
hemorrhagic stroke, and surgery within the past month (Table 2).2

In addition to those patients with contraindications to fibrinolysis, there are 4 other patient populations traditionally considered for surgical pulmonary embolectomy. Patients with massive or submassive PE in whom systemic or catheter-based therapies have failed are appropriate candidates for surgical pulmonary embolectomy. These patients are at increased risk for further clinical deterioration, and those patients who proceed directly to surgery have improved outcomes in comparison with those who undergo repeat fibrinolysis.18 When considering surgical pulmonary embolectomy after failed fibrinolysis, the urgency of the need for intervention must be weighed against the risk of bleeding. Second, patients with clot-in-transit in the right atrium or RV have an estimated mortality rate of 29% and are at high risk for abrupt hemodynamic deterioration, often without warning and with little time to administer fibrinolytic therapy or mobilize an interventional cardiology team (Figure 3 and Movie I in the online-only Data Supplement).19

Third, patients with a large patent foramen ovale have worse outcomes than patients without, with relative risks of death and ischemic stroke of 2.4 and 5.9, respectively.20 Proceeding to surgery rather than attempting fibrinolysis allows for an opportunity to repair the patent foramen ovale to prevent paradoxical embolism in the future. Finally, patients with submassive PE and moderate-to-severe right heart strain may benefit from the immediate hemodynamic improvement in pulmonary vascular resistance and RV pressure overload provided by surgical pulmonary embolectomy.13–15

### Imaging Evaluation of Patients Undergoing Surgical Pulmonary Embolectomy

The imaging test of choice for PE is contrast-enhanced CT. In addition to making the diagnosis of PE, CT also provides anatomic information that identifies the location and extent of the PE. Large central PE is defined as being present within the lateral mediastinal borders and will be accessible through surgical pulmonary embolectomy, whereas small peripheral PE will not be.17 For patients with a PE identified by using ventilation-perfusion lung scanning who cannot undergo contrast-enhanced CT owing to a dye allergy or other contraindications, transesophageal echocardiography can be used to assess for clot-in-transit or the presence of PE in the proximal pulmonary arteries. If the anatomy is not clear to the surgical team, imaging should be reviewed with experienced chest or cardiovascular imaging specialists. Often, multiplanar reformatted images provide additional information to guide the operative approach.

### Major Indications for Surgical Pulmonary Embolectomy

- Massive or submassive centrally located pulmonary embolism with any of the following:
  - Contraindication to fibrinolytic therapy
  - Active bleeding
  - Failed fibrinolysis or catheter-based therapy
  - Clot-in-transit
  - Large patent foramen ovale
  - Moderate-to-severe right ventricular dysfunction

<table>
<thead>
<tr>
<th>Table 1. Major Indications for Surgical Pulmonary Embolectomy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Massive or submassive centrally located pulmonary embolism with any of the following:</td>
</tr>
<tr>
<td>- Contraindication to fibrinolytic therapy</td>
</tr>
<tr>
<td>- Active bleeding</td>
</tr>
<tr>
<td>- Failed fibrinolysis or catheter-based therapy</td>
</tr>
<tr>
<td>- Clot-in-transit</td>
</tr>
<tr>
<td>- Large patent foramen ovale</td>
</tr>
<tr>
<td>- Moderate-to-severe right ventricular dysfunction</td>
</tr>
</tbody>
</table>

### Major Contraindications to Systemic Fibrinolysis

- Active bleeding
- Recent neurological, spinal, or craniofacial surgery or injury to the head or face
- Any past history of intracranial hemorrhage
- Intracerebral malignancy, mass, aneurysm, or arteriovenous malformation
- Ischemic stroke within the past 3 mo
- Major surgery within the past month
- Noncompressible vascular punctures or trauma
- Prolonged cardiopulmonary resuscitation
- Current severe hypertension or past history of prolonged severe hypertension
- Age >75 y or dementia
- Pregnancy

<table>
<thead>
<tr>
<th>Table 2. Major Contraindications to Systemic Fibrinolysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Active bleeding</td>
</tr>
<tr>
<td>• Recent neurological, spinal, or craniofacial surgery or injury to the head or face</td>
</tr>
<tr>
<td>• Any past history of intracranial hemorrhage</td>
</tr>
<tr>
<td>• Intracerebral malignancy, mass, aneurysm, or arteriovenous malformation</td>
</tr>
<tr>
<td>• Ischemic stroke within the past 3 mo</td>
</tr>
<tr>
<td>• Major surgery within the past month</td>
</tr>
<tr>
<td>• Noncompressible vascular punctures or trauma</td>
</tr>
<tr>
<td>• Prolonged cardiopulmonary resuscitation</td>
</tr>
<tr>
<td>• Current severe hypertension or past history of prolonged severe hypertension</td>
</tr>
<tr>
<td>• Age &gt;75 y or dementia</td>
</tr>
<tr>
<td>• Pregnancy</td>
</tr>
</tbody>
</table>

### Management of Patients Undergoing Surgical Pulmonary Embolectomy

On diagnosis of PE, all patients without contraindications should be administered immediate therapeutic dose anticoagulation to prevent thrombus propagation and further embolic events. Intravenous unfractionated heparin administered as a bolus and then an infusion titrated to an activated partial thromboplastin time of 60 to 80 seconds is preferred if surgical pulmonary embolectomy is being considered. Continuous infusion intravenous unfractionated heparin allows for hour-to-hour control of the intensity of anticoagulation. During cardiopulmonary bypass, an activated clotting time target of ≥2400 seconds is required. Typically, a pulmonary arteriotomy is made longitudinally in the main pulmonary artery distal to the pulmonic valve and short of the pulmonary artery bifurcation. A saddle PE will be visualized via this incision, and gentle traction is often successful in removing the saddle PE and associated left pulmonary artery thrombus. If residual thrombus is suspected in the right pulmonary artery, an additional incision can be made in the right pulmonary artery between the aorta and superior vena cava to retrieve additional thrombus. Blind exploration of the fragile pulmonary arteries should be avoided. Centers offering surgical pulmonary embolectomy should not only have expertise in performing the surgery, but also experience in the postoperative support of these patients and management of potential complications. Major complications can include persistent RV dysfunction, resulting in failure to wean from cardiopulmonary bypass, and cardiac tamponade, sternal wound infection, and postoperative bleeding, as well.

Multiple studies have documented a high rate of recurrent PE in patients after surgical pulmonary embolectomy, and these events can be life-threatening in the presence of preexisting RV failure.13–15 In the International Cooperative Pulmonary Embolectomy Registry, patients who underwent IVC filter placement had a lower 90-day mortality,21 and it has become standard
practice at some centers to insert IVC filters intraoperatively or immediately postoperatively in patients who undergo surgical pulmonary embolectomy. Whether and when to retrieve IVC filters inserted perioperatively remains subject to debate.

Postoperatively, anticoagulation should be restarted promptly to prevent propagation of deep vein thrombosis or distal PE. Oral anticoagulation is then instituted with warfarin or a non–vitamin K antagonist oral anticoagulant. The duration of anticoagulation should take into account the circumstances surrounding the PE. However, extended-duration anticoagulation is often considered in unprovoked (idiopathic) PE or in patients with life-threatening PE presentation.

**PE Response Teams**

Because of the complexities of patient selection for advanced therapies in acute PE, many centers have instituted multidisciplinary PE response teams. These teams bring together experts in cardiovascular medicine, cardiothoracic surgery, echocardiography, emergency medicine, radiology, and pulmonology to select appropriate patients for advanced therapies and to determine the optimal reperfusion strategy. The use of these multidisciplinary teams may allow rapid access to advanced therapies such as surgical pulmonary embolectomy when appropriate.

**Case Follow-Up**

The patient underwent successful urgent surgical pulmonary embolectomy (Figure 4). With rapid improvement in his oxygenation and hemodynamic status, he was extubated the following morning. An IVC filter was placed postoperatively. At the time of hospital discharge, the patient was transitioned from intravenous unfractionated heparin to oral rivaroxaban 20 mg daily. In vascular medicine clinic follow-up, he had returned to his baseline functional status and was free of dyspnea.

**Disclosures**

None.

**References**


Surgical Pulmonary Embolectomy
Timothy J. Poterucha, Brian Bergmark, Sary Aranki, Tsuyoshi Kaneko and Gregory Piazza

Circulation. 2015;132:1146-1151
doi: 10.1161/CIRCULATIONAHA.115.015916

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/132/12/1146

Data Supplement (unedited) at:
http://circ.ahajournals.org/content/suppl/2015/09/21/CIRCULATIONAHA.115.015916.DC1

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Circulation can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Circulation is online at:
http://circ.ahajournals.org//subscriptions/
SUPPLEMENTAL MATERIAL

**Video.** Transthoracic echocardiogram, apical four chamber view, showing a mobile echodensity (“clot-in-transit”) extending from the right atrium into the right ventricle (RV). The RV is dilated with free wall hypokinesis and preserved contractility at the apex (McConnell’s sign). There is interventricular septal deviation to the left in systole, consistent with RV pressure overload.