Catheter-Assisted Pulmonary Embolectomy
Piotr Sobieszczyk, MD

**Case presentation:** A 65-year-old man presented to the emergency department after a fall and was diagnosed with a fracture of the right femoral neck. He was scheduled for surgical repair the following day. During positioning for arthroplasty, he developed hypotension, tachycardia, and hypoxia, followed by pulseless electric activity. He was resuscitated and maintained on epinephrine and norepinephrine infusions. A transesophageal echocardiogram revealed a dilated and hypokinetic right ventricle with preserved apical contractility (Figure 1). Massive pulmonary embolism (PE) was suspected. What are the therapeutic options for this critically ill patient?

Patients afflicted with massive PE have 90-day mortality rates approaching 50%. Massive PE is defined by sustained hypotension (<90 mm Hg for a minimum of 15 minutes, or requirement for inotropic support), pulselessness, or bradycardia with signs of shock. As many as 10% of patients with submassive PE can develop hemodynamically significant and life-threatening right ventricular failure. In such cases, supportive care and anticoagulation must be accompanied by rapid reduction of right ventricular (RV) afterload and restoration of adequate cardiac output. Many patients with submassive PE and stable blood pressure develop residual RV dysfunction and experience a decline in functional status at 6-month follow-up. Acute relief of RV strain and reduction of thrombotic burden in the pulmonary arteries could yield long-term benefit in this group.

Pharmacological and invasive strategies for reduction of thrombotic burden in the pulmonary arteries have been used for many decades with variable success.

Systemic intravenous thrombolysis has been shown to be of benefit in small trials of patients with massive PE, but it failed to reduce short-term mortality and morbidity in a wide range of patients with submassive PE. Thrombolytic therapy is widely available and easy to administer, but these attributes are offset by the obligatory 2-hour infusion, a costly delay when immediate effect is required. Contraindications to systemic thrombolysis are present in as many as 50% of patients, and major bleeding complications can occur in 20% of patients, further limiting the utility of this therapy. Surgical embolectomy, first conceived by Trendelenburg in 1908 and performed by Kirschner in 1924, can be life saving in patients with clot burden in the proximal pulmonary artery (PA). Advances in surgical and anesthesiology techniques have reduced perioperative mortality to 20%, but the best outcomes are achieved in a few selected centers with dedicated, rapid-response embolectomy programs.

Percutaneous strategies for treatment of massive and submassive PE date back to the development of the Greenfield suction catheter in the 1960s. Technical advances in endovascular devices now allow for combining mechanical thrombus disruption and aspiration with pharmacological thrombolysis. This is called pharmacomechanical therapy. Pharmacological therapy allows rapid reduction in RV afterload in patients with hemodynamic instability, whereas mechanical therapy reduces thrombus burden via longer, catheter-directed infusion of a low-dose thrombolytic. There is a growing interest in clinical applications and large-scale investigations of these pharmacomechanical therapies in patients with massive PE and selected patients with submassive PE. This Clinician Update will examine the rationale for catheter-based pulmonary embolectomy and describe endovascular techniques commonly used today.

**Rationale for Catheter-Assisted Pulmonary Embolectomy**
Catheter-based therapies can be rapidly instituted in most medical centers.
equipped with cardiac and interventional radiology suites in a system akin to one used for treatment of ST-elevation myocardial infarction. Less invasive percutaneous procedures are better tolerated in tenuous patients whose comorbidities frequently preclude consideration of surgical embolectomy. Although many patients cannot tolerate large doses of systemic thrombolysis, catheter-based interventions allow administration of significantly reduced thrombolytic doses directly into the PA. Thrombolytics can be directly infused into the pulmonary circulation at doses that are a fraction of those used for systemic thrombolysis. Tenecteplase and tissue plasminogen activator (tPA) have replaced streptokinase and urokinase as thrombolytics of choice. Over 60% of catheter-assisted interventions include local administration of thrombolytics, which increase clinical success rates.10

The disadvantage of endovascular therapies lies in the size mismatch between the caliber of the proximal pulmonary arteries and the size of endovascular devices designed for thrombus removal from much smaller coronary or peripheral vessels or dialysis fistulas. In addition, to be accessible to catheter-assisted embolectomy, the PE has to be located in the main PAs or in the proximal segmental branches. The organized thrombotic cast of a femoral vein lodged in the PA (Figure 2) can be resistant to mechanical techniques developed to deal with fresh and soft thrombus formed on a ruptured atherosclerotic plaque. The addition of prolonged direct infusion of thrombolytic agents is a critical component of these procedures. Even partial mechanical removal and fragmentation of thrombus, however, can be sufficient to restore RV function and reverse circulatory collapse, especially when accompanied by an additional infusion of low dose thrombolytic into the PA (Figure 3).

Catheter-Assisted Embolectomy Techniques

The ideal pulmonary embolectomy device would facilitate removal of a large volume of thrombus through small-caliber venous access with exposure to small doses of thrombolytic agents. Because such a device does not exist at present, several hybrid techniques have been developed to restore PA patency (Figure 4).

Catheter-Mediated Fragmentation

The expectation that simple disruption and fragmentation of proximal thrombus can restore RV function rests on the premise that the cross-sectional area and volume of more distal PA branches is larger than that of the proximal vessel. Thus, breaking up a large thrombus and redistributing the obstruction into smaller distal branches will reduce the RV afterload and increase the surface area exposed to pharmacological or intrinsic lytic action. This concept was first tested by Brady et al in 199111 who successfully used standard coronary catheters to fragment proximal thrombus in 3 patients with massive PE. An alternative technique described by Schmitz-Rode et al12 involves manual spinning of an angiographic pigtail catheter in the main PA. A long, 80- to 90-cm sheath resting in the proximal PA facilitates advancement of a 100- to 125-cm pigtail catheter over a wire exiting through its proximal side-hole. The shape of the curly pigtail is thus retained as the catheter rotates on a wire like a propeller, churning the thrombus into smaller pieces. Several series have described clinical success with the use of this approach, reporting both angiographic reductions in the degree of obstruction, and hemodynamic improvement, as well.13

Fragmentation strategies are particularly effective when combined with thrombolytic infusion directly into the PA.14 Most frequently, fragmentation of the thrombus is accomplished by combining several techniques such as balloon angioplasty, rotational fragmentation, and aspiration of smaller distal fragments with 8F coronary catheters. In clinical practice, delivery of thrombolytic agents can be accomplished by placing multiholed infusion catheters in each affected PA and infusing tPA at 1 to 2 mg/h over a period of 12 to 18 hours. Combined pharmacological and mechanical techniques account for 69% of all catheter-
assisted procedures reported over the past decade.\(^{10}\)

**Catheter-Based Thrombectomy**

Several devices designed to macerate and simultaneously aspirate thrombus from smaller vessels have been used in the pulmonary arteries. The Aspirex thrombectomy catheter available outside the United States (Straub Medical AG) uses a spiral rotating at 40,000 rpm to fragment the thrombus into smaller particles, which are then aspirated through an adjacent port as the device is advanced and withdrawn through the thrombus. The rotational speed can be adjusted to prevent excessive suction and collapse of the vessel wall around the rotating spiral. Pulmonary application of this device was first described by Kucher et al\(^{15}\) and subsequently shown to be safe and effective in a small clinical series.\(^{16}\) The Amplatz-Helix thrombectomy catheter (eV3, Inc, MN) and the Hydrolyzer catheter (Cordis, NJ) were designed for treatment of thrombosed hemodialysis fistulas. The Helix device uses an impeller spinning at 150,000 rpm to suck in the thrombus, fragment the clot into smaller pieces, and expel the pieces through the side-holes without aspirating them. The device cannot be advanced over a wire, and the clinical experience is quite limited with case series reporting primarily angiographic improvements.\(^{17}\) The Hydrolyzer device uses the Venturi effect to create a vacuum by infusing saline at high pressure as the catheter advances and retreats through the thrombus. This pigtail-tipped catheter is manually rotated and the thrombus fragmented and aspirated. Clinical experience is limited to a few small series.\(^{18}\)

The largest clinical experience in pulmonary thrombectomy procedures comes from applications of the Angiojet rheolytic thrombectomy catheter (Medrad Interventional, PA). This device relies on the Bernoulli principle to generate a vacuum in the low-pressure zone behind a series of high-pressure saline jets positioned at the tip of the catheter. The saline jets disrupt the thrombus, which is then aspirated in the vacuum zone. A unique feature of this catheter allows forceful spraying of a thrombolytic agent instead of saline without simultaneous aspiration. In this mode, the catheter is advanced through the thrombus, lacing it with 5 to 10 mg of tPA. This pulse-spray treatment facilitates standard thrombectomy performed after a pause of 15 to 30 minutes to allow the thrombolytic agent to take effect. Since the initial description of this device used or treatment of PE by Koning et al in 1997,\(^{19}\) the published experience comprises >140 patients with massive and submassive PE. The largest series included 50 patients with combined catheter-directed thrombolysis used in 30% of treated patients.\(^{20}\) Primary outcome measures have varied from series to series, with mortality ranging from 12% to 25% in a heterogeneous patient population. Its wide application in coronary and peripheral arterial and venous interventions fueled its popularity in PE interventions. When used in the pulmonary and coronary vessels, the release of adenosine from disrupted platelets can lead to bradycardia, pulmonary vasoconstriction, and worsening hypoxia. These concerns have led to an US Food and Drug Administration black-box warning regarding intrapulmonary interventions with this device. Temporary transvenous pacing and brief treatment runs, and aminophylline administration, as well, can effectively overcome these side effects, allowing successful use of this device with or without thrombolysis.

**Ultrasound-Assisted Therapies**

Traditional catheter-based thrombolysis techniques used catheters with multiple side-holes passively infusing thrombolytic into the thrombosed arterial or venous segment. Ultrasound energy has been shown to disrupt the structure of the thrombus and render it more susceptible to thrombolytic agents. Although high-energy ultrasound can mechanically fragment the clot, lower-energy applica-
tion dissociates fibrin strands to allow more effective thrombolysis with shorter and lower-dose administration. The latter strategy is used by the EKOS device (EkoSonic Endovascular), which combines a catheter with numerous sideholes infusing thrombolytic and a filament with multiple miniature ultrasound transducers. The filament is placed in the catheter’s central lumen and emits ultrasound at 2.2 MHz along the treatment zone (Figure 5). This catheter can be used as adjunctive treatment after initial fragmentation or as a standalone strategy of ultrasound-assisted, catheter-directed thrombolysis in more stable patients. Initial experience suggests that 24-hour infusion of tPA at doses $\frac{1}{H11021} \times 1 \text{ mg/h}$ can achieve complete thrombus resolution in 76% of patients and near-complete resolution in an additional 18%. Even shorter treatments of 17 hours with mean tPA doses of 0.86 mg/h effectively reduce the Miller score and result in larger thrombus resolution in comparison with higher rates and longer infusions via traditional, passive infusion catheters.

In a retrospective series of 24 patients with massive and submassive PE, a 12-hour treatment with the EKOS catheter infusing as little as 20 mg of tPA resulted in a statistically significant reduction in the RV to left ventricle ratio.

Suction Embolectomy

The optimal endovascular intervention would succeed in near-complete removal of pulmonary arterial thrombus without the risk of hemolysis, release of vasoactive agents, or distal embolization. The Greenfield embolectomy catheter is used to achieve this goal by combining a large-caliber catheter with a suction cup at its end and a syringe to generate suction. Green-
large caliber size requires either surgi-
returns it via another catheter. The
tion of 3 L/min, filters the blood, and
system, where a pump generates suc-
resembling a cardiopulmonary bypass
its tip that is connected to a circuit
debris and consists of a large-caliber
by US Food and Drug Administration
embolectomy. The device is approved
early success could not be replicated.
spite technical improvements, the cath-
crease in cardiac output,25 but, de-
field’s early experience showed signif-
icant reductions in PA pressures and
crease in cardiac output,25 but, de-
the catheter with multiple side-holes, and the ultrasound-emitting
B. The catheter is placed in the
right and left lung. Note the multiple
ultrasound emitters along the length of
the catheter (arrow).
insertion. The stiff catheter can be
difficult to advance to the PA.

Complications of
Catheter-Based
PE Interventions
Many complications of PE interventions
are intrinsic to the pulmonary anatomy
and are independent of the type of device
used. The thin-walled PA branches are
prone to perforation, prompting many
clinicians to recommend limiting inter-
ventions to the main PA and the larger
segmental branches of the lower lobes.
Perforation can result in pericardial tam-
ponation or life-threatening hemoptyis.
Concomitant use of even low doses of
thrombolytic agents carries the risk of
bleeding complications, but cumulative
experience suggests that major proce-
dural complications, including bleeding,
can be as low as 2.4%.10 Catheter frag-
mentation techniques have been reported
to cause paradoxical elevation of pulmo-
ary arterial pressures and worsening
hemodynamic status, likely via emboli-
zation of proximal thrombus into the
distal branches.26,27 Some of the compi-
lcations are device specific. The Angiojet
device may be associated with higher
rates of perioperative complications,
particularly bradycardia and hemoglo-
bininuria.10 There is, however, no head-to-
head comparison of the various endovas-
cular techniques to assess their relative
safety.

Challenges and
Future Directions
Catheter-assisted, pharmacomechani-
cal pulmonary thrombectomy has not
been rigorously studied as a viable
strategy. This is largely be-
cause of low interest in treating venous
thromboembolic disease among car-
diovascular specialists, complex and
heterogeneous patient groups who ex-
perience PE, and lack of an optimal
percutaneous device to treat the large
volume of organized thrombus in the
pulmonary arteries. None of the de-
ces or catheters commonly used to-
day are approved by the US Food and
Drug Administration. Numerous com-
binations of endovascular techniques
have been described in small clinical
series, but few have used uniform out-
come metrics, reliably differentiated
between massive and submassive PE,
or compared devices with each other,
with surgical embolectomy, or with
medical therapy.

The cumulative contemporary expe-
rience in patients with massive PE
comprises ~35 predominantly retro-
spective series totaling 594 patients
and suggests that catheter-assisted
therapies are safe and lead to hemody-
namic resolution of hypoxia and sur-
vival to hospital discharge in as many
as 86% of patients with massive PE.10
Optimal use of catheter-assisted embo-
lectomy in these patients demands the
introduction of a system capable of
rapid diagnosis, triage, and treatment
in a manner mirroring the treatment of
patients with ST-segment elevation
myocardial infarction. Rigorous pro-
spective data are needed to standardize
endovascular therapy and determine
patient subgroups that may benefit
from endovascular therapy as opposed
to systemic thrombolysis.

The growing experience in the en-
dovascular treatment of PE demands a
concerted effort toward a systematic
and prospective evaluation of these
therapies to determine which strategies
are most beneficial and which patients
benefit the most.

Case Resolution
This patient was immediately transferred
to the cardiac catheterization laboratory.
Pulmonary angiography revealed throm-
buses occluding the right and left lower
lobe pulmonary arteries. Pulmonary ar-
tery pressure was elevated at 47/
13 mm Hg. Pulse-spray thrombectomy
with the use of the Angiojet catheter
resulted in significant resolution of the
thrombus. Pulmonary artery pressure de-
creased to 30/15 mm Hg, and inotropic
support was discontinued. Additional
catheter-directed thrombolysis was per-
fomed in each lung with a low dose of
tPA over the course of 18 hours. A
retrievable inferior vena cava filter was
placed in anticipation of hip surgery. He
was extubated the following day. Suc-
cessful open reduction and internal fixation of the hip was performed 6 days later. He was discharged to a rehabilitation facility on warfarin therapy without the need for supplemental oxygen.

Endovascular therapy was chosen over surgical embolectomy because it could be rapidly implemented in this patient in extremis. Systemic thrombolysis was deemed to be relatively contraindicated because of the risk of bleeding at the site of hip fracture. This clinical case highlights some of the advantages of catheter-based interventions: rapid initiation of therapy, very low doses of adjunctive thrombolytic therapy, and the expectation of rapid hemodynamic improvement in patients with an acute thrombotic event. The choice among the 3 treatment modalities should depend on local expertise, patient characteristics, and the speed with which they can be applied.

Disclosures
None.

References
3. Stein PD, Matta F, Janjua M, Yekoub AY, Jaweesh F, Alrifai A. Outcome in stable patients with acute pulmonary embolism who had right ventricular enlargement and/or elevated levels of troponin I. Am J Cardiol. 2010;106:558–563.

Key Words: pulmonary embolism ■ thromboembolism ■ thrombolysis ■ thrombus aspiration
Catheter-Assisted Pulmonary Embolectomy
Piotr Sobieszczyk

Circulation. 2012;126:1917-1922
doi: 10.1161/CIRCULATIONAHA.110.963041
Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 2012 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

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/126/15/1917

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/