

Chronic Thromboembolic Pulmonary Hypertension: A Comprehensive Review and Multidisciplinary Approach to Surgical Treatment

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ABSTRACT: Chronic thromboembolic pulmonary hypertension (CTEPH) is an underdiagnosed and undertreated sequelae of acute pulmonary embolism. In this comprehensive review, we provide an introductory overview of CTEPH, highlight recent advances in its diagnostic imaging, and describe the surgical technique for pulmonary thromboendarterectomy (PTE), the only established curative treatment for CTEPH. We also discuss the emerging role of balloon pulmonary angioplasty, both independently and combined with PTE, for patients with inoperable, residual, or refractory pulmonary hypertension post PTE. Finally, we stress the importance of a specialized multidisciplinary team approach to CTEPH patient care and share our approach to optimizing care for these patients.

INTRODUCTION

Group 4 pulmonary hypertension (PH) is defined by an elevated pulmonary arterial pressure of > 20 mm Hg at rest, a pulmonary vascular resistance (PVR) of > 3 Wood units, and a wedge pressure < 15 mm Hg. The unifying physiologic mechanism of the numerous causes of PH is increased PVR. Thus, the World Health Organization has classified PH into five groups by etiology.¹

- Group 1: Pulmonary arterial hypertension (PAH)
- Group 2: PH due to left heart disease
- Group 3: PH due to lung disease and/or hypoxia
- Group 4: PH due to pulmonary artery obstructions
- Group 5: PH due to unclear and/or multifactorial mechanisms

The subject of this review article is chronic thromboembolic hypertension (CTEPH), and while group 4 PH does not strictly require the presence of a chronic clot, this is the primary etiology and manifestation of PH in group 4. Among the five groups of PH, only CTEPH is potentially curable, and it is particularly important to identify because its management strategy is unique compared with other forms of PH. Early identification and treatment of CTEPH is critical for successful patient outcomes. However, it is challenging to diagnose clinically because of its nonspecific symptoms with a wide differential. Of note, prospective trials are needed to determine whether group 4 PH from thromboembolic disease would benefit from specific management.¹

This review article provides a clinical guide to managing CTEPH, from diagnostic workup and treatment options to our institutional experience in surgical decision making and optimizing CTEPH patient care through multidisciplinary collaboration.

PATHOPHYSIOLOGY

CTEPH is a condition in which PH arises from unresolved, precapillary thromboembolic disease.² The natural history of acute pulmonary embolism (PE) usually results in the complete resolution of pulmonary thrombi with return to baseline pulmonary hemodynamics. In rare cases, chronic and incomplete resolution of these thrombi induces vascular remodeling and formation of fibrotic scar tissue in central pulmonary vessels.³ Although most of the clot burden typically resolves in these cases, a significant number of patients had more than 30% of segments still obstructed at 3 months, as shown on perfusion scan.⁴ Consequently, the persistence of these flow-limiting thrombi at various levels of the pulmonary vascular bed increases PVR, leading to increased pulmonary pressure that, left untreated, causes right heart failure and ultimately death.

EPIDEMIOLOGY AND RISK FACTORS

While many studies have examined the incidence and risk factors contributing to CTEPH, its true incidence is hard to pinpoint. Estimates vary from between 1% and 5% and depend on the patient population studied, study design, and CTEPH definition. Retrospective studies have estimated CTEPH incidence at approximately 1% among patients with PE.⁵ Prospective studies that examine these patients at annual follow-up estimate a CTEPH incidence between

3% and 5%.^{6,7} A recent meta-analysis of 16 studies estimates a prevalence of 0.5% in the general population and 3% in PE survivors.⁸ Given that the estimate of PE incidence in the United States is 300,000 per year, even the most conservative estimate projects at least 3,000 new cases of CTEPH per year. Even so, this projection does not account for 25% of CTEPH patients with no prior history of PE.⁹ One prospective Chinese study following 239 first-time PE patients over 5 years revealed a CTEPH incidence of 11.2% and 4.5% from 3 months to 3 years, suggesting that the actual incidence of PE may be much higher than previously reported.¹⁰ Together, these data show that there is a very large unmet need in CTEPH diagnosis and treatment. Since CTEPH often goes undetected and underdiagnosed, it is up to the astute clinician to perform a thorough evaluation to detect and treat the disease in a timely fashion.

CTEPH is a relatively rare outcome in PE, suggesting that other risk factors play a role in its development. For example, several coagulopathies and hypercoagulable states are associated with CTEPH, including elevated antiphospholipid antibodies and factor VIII.^{11,12} However, there is no difference in levels of antithrombin III, protein C and S, and factor V Leiden among the general population and patients with CTEPH.¹³ Other less common factors thought to be associated with CTEPH development include history of splenectomy, presence of ventriculoarterial shunts, chronic systemic inflammatory disorders, malignancy, and iatrogenic infections such as pacemaker leads or dialysis catheters.^{14,15}

While numerous risk factors have been associated with CTEPH, none are sensitive or specific enough to independently warrant CTEPH evaluation in patients with a history of PE. One clinical prediction model suggests that unprovoked PE and a > 2 week delay in diagnosis from symptom onset increases the risk for developing CTEPH.¹⁶ Research is ongoing to determine a risk classification for CTEPH at the time of acute PE diagnosis.

CLINICAL PRESENTATION

Making a diagnosis of CTEPH can be challenging because it has no specific signs or symptoms. Patients with CTEPH most commonly present with progressive dyspnea and fatigue, which can be mistaken for other diagnoses. Furthermore, a history of PE is often absent. As the disease progresses, the increasing PH eventually leads to nonspecific physical findings of right ventricular failure, including peripheral edema, jugular venous distension, ascites, and hepatomegaly. Due to its nonspecific clinical picture and lack of awareness of the disease, CTEPH is usually diagnosed late in the disease, when right heart failure has already occurred. Given this insidious natural

history of disease, any patient who is functionally limited or symptomatic 3 to 6 months post-acute PE or who is undergoing workup for cause of PH should be referred for evaluation for CTEPH.

In a patient with documented PE and proper anticoagulation management, resolution of clots and symptomatic improvement usually occurs within the first 3 to 6 months.¹⁷ According to the European CTEPH registry, the median time from initial onset of symptoms to CTEPH diagnosis is 14 months, reflecting the insidious progressive nature of the disease.⁹ Thus, persistent symptoms with relevant history should prompt the clinician to pursue additional CTEPH workup.

TEAM MANAGEMENT

The diagnosis and management of CTEPH is a complex task requiring referral to a specialized center that can provide optimized care through multidisciplinary collaboration. The team should include all those who are actively involved in assessing the patient, formulating the workup plan, and performing and interpreting diagnostic tests. For longitudinal care, the same team should carry full responsibility for both medical and surgical management of CTEPH. At Houston Methodist Hospital, we have established a dedicated CTEPH team that includes cardiac surgery, pulmonology, interventional cardiology, anesthesia, critical care, radiology, and a nursing coordinator. Together, the team runs a CTEPH clinic once a month for new patient evaluation and established patient follow-up, and they meet the first Monday of each month to discuss all patient updates and test results. In this meeting, the team also plans and coordinates management of patients scheduled for surgical pulmonary thromboendarterectomy. We prioritize scheduling of these surgeries for the beginning of the week, which allows the entire CTEPH team to round daily on each patient in the early postoperative period, which is typically the most eventful time for this complex condition.

CLINICAL WORKUP

As previously mentioned, diagnosing CTEPH from a history and physical exam can be challenging due to its nonspecific clinical presentation and the coexistence of other comorbidities. CTEPH should remain on the differential for any patient with progressive dyspnea and other related cardiopulmonary symptoms with unknown origin, regardless of history of PE. Leading up to CTEPH diagnosis, a general workup for PH must be performed to exclude other causes of PH and to assess for other comorbidities.¹⁸ Whenever CTEPH is suspected, diagnostic tools should be considered, and early referral to an experienced center

should be initiated. Depending on the level of expertise and resources available, diagnostic workup may include echocardiography, lung ventilation-perfusion scintigraphy, computed tomography (CT), and right heart catheterization (RHC).

At our own institution, we prefer RHC, left heart catheterization (LHC), and pulmonary arteriogram. For more on this topic, see “Evaluation, Diagnosis, and Classification of Pulmonary Hypertension” by Beshay et al. in this issue.

IMAGING

Echocardiography

Echocardiography is a readily available initial diagnostic tool. While it alone cannot diagnose CTEPH, it can indirectly measure pulmonary artery pressure (PAP). It is also useful in visualizing other cardiac signs of PH, including dilated right heart chambers, right ventricular systolic dysfunction, and paradoxical movement of the septum. Echocardiography is also essential to rule out other causes of PH, including intracardiac shunting and underlying left heart dysfunction. Importantly, contrast echocardiography, also known as a bubble study, must be ordered to assess intracardiac shunting. Finally, echocardiography is an important tool for monitoring improvement in patients with acute PE who develop PH and reduced right heart function.

Ventilation-Perfusion Lung Scan

A normal ventilation-perfusion (V/Q) scan is sufficient to exclude CTEPH, with a sensitivity of 90% to 100% and specificity of 94% to 100%.¹⁷ On V/Q scan, CTEPH presents as normal ventilation with a wedge-shaped perfusion deficit (Figure 1). This deficit is usually seen bilaterally, and unilateral absence of perfusion should increase suspicion of other conditions, such as malignancy, lung fibrosis, or vasculitis. Data from the international CTEPH registry indicates that 98% of CTEPH patients have abnormal perfusion scans while around 20% have abnormal ventilation scans.⁹ With improvements in CT technology, the advantage of V/Q over CT in detecting CTEPH has narrowed dramatically. However, V/Q scanning remains the preferred method for CTEPH screening as it requires less radiation and has less contrast-related adverse events. The main disadvantage of V/Q scanning is that it can underestimate the effect of an incomplete occlusion.

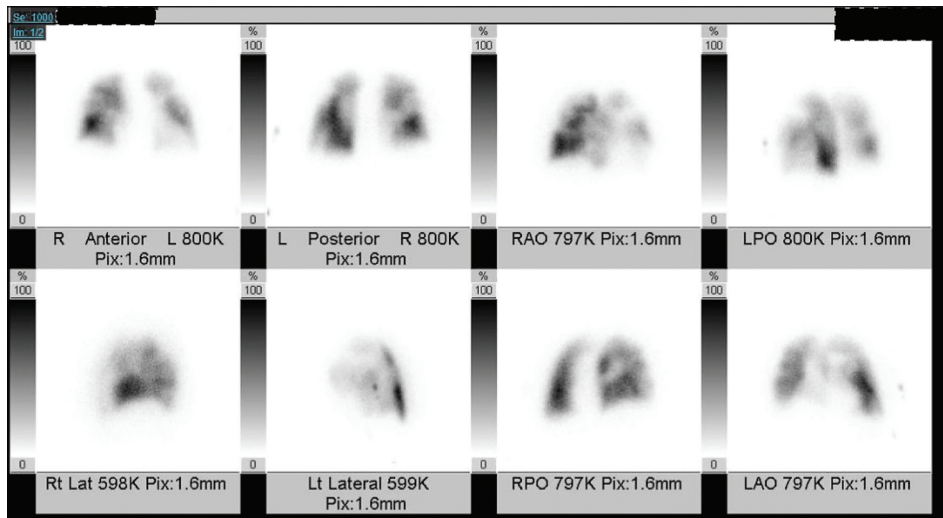


Figure 1. Ventilation-perfusion scan of patient with thromboembolic pulmonary hypertension showing multiple wedge-shaped perfusion deficits bilaterally.

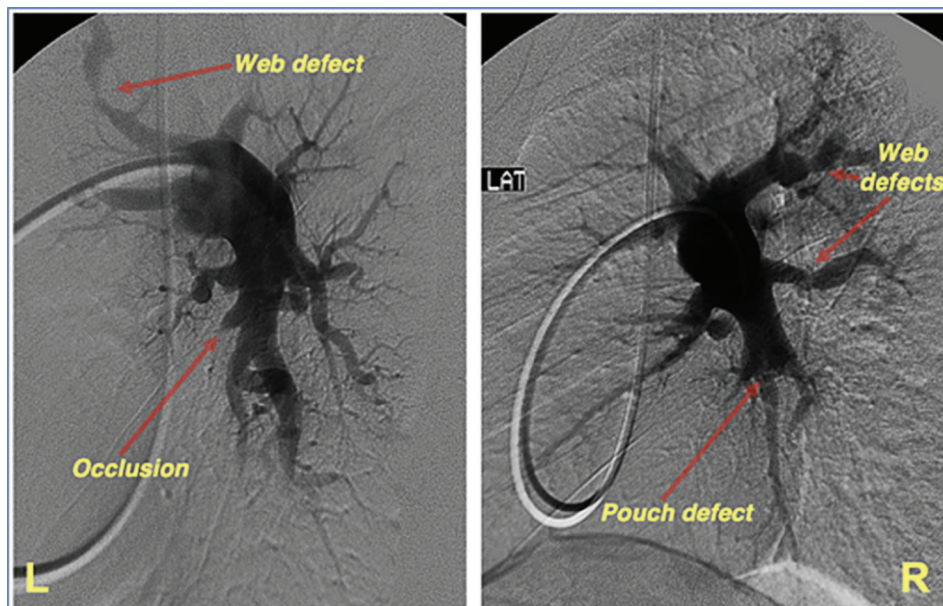


Figure 2. Digital subtraction angiograms demonstrating multiple webs, vessel occlusions, and pouch defects consistent with thromboembolic pulmonary hypertension.

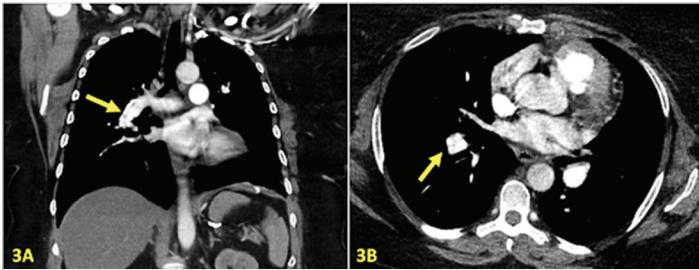


Figure 3.

(A) Coronal and (B) axial computed tomography demonstrating a web-like filling defect in a 52-year-old female with thromboembolic pulmonary hypertension.

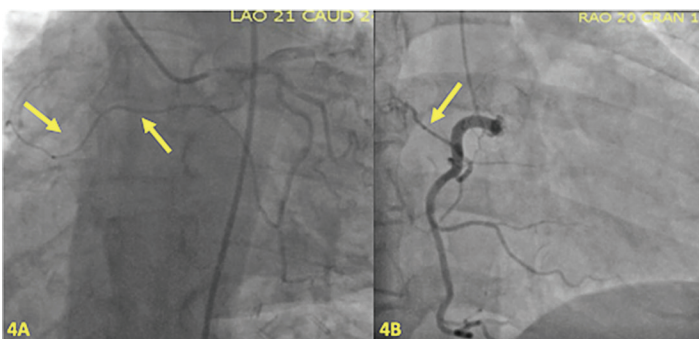


Figure 4.

Bronchial collateralization from (A) the left circumflex artery and from (B) the conus branch of the right coronary artery.

CT Pulmonary Angiogram

CT pulmonary angiogram (CTPA) is the gold standard of diagnostic imaging for acute PE. It is also quite reliable in detecting and evaluating the extent of thromboembolic disease for assessing operability in CTEPH. Even so, a negative CT scan does not entirely rule out the diagnosis of CTEPH. However, CTPA has excellent sensitivity and specificity for detecting thromboembolic disease at lobar (97-100% and 95-100%, respectively) and segmental levels (86-100% and 93-99%, respectively)¹⁹⁻²¹ when read by an experienced cardiothoracic radiologist. CTEPH on CTPA has distinct features that can help discern the chronicity of thrombi compared to acute PE. The visualized filling defect is usually eccentric and web-like, which can occur after partial recanalization of the thrombosis (Figures 2, 3).

Unlike acute PE, where the occluded vessel is expanded around the clot, the surrounding vessel in CTEPH is retracted and atrophied. Additionally, partially stenotic or occluded pulmonary vasculature may demonstrate adjacent poststenotic dilation while total occlusion results

in “pouching defects,” a convex ballooning where the distal vessel is cut off.²² Other radiologic signs of CTEPH on CTPA include healed lung infarct, cylindrical bronchiectasis, and calcified thrombi.²³ Enlarged pulmonary arteries, mosaicism, and bronchial collaterals are other signs consistent with CTEPH and can help rule out mimickers of CTEPH (eg, angiosarcoma). The cardiothoracic radiology team at our institution has proposed a standardized protocol to combine perfusion scan with CT in the workup of all suspected CTEPH patients.

Dual-Energy Computed Tomography

Dual-energy computed tomography (DECT) is an emerging tool in the workup of CTEPH patients. Its basic principle is to capture iodine attenuation by simultaneous low (70-100 kV) and high (140-150 kV) tube voltage without additional radiation or contrast, and this data is used to generate a perfused blood volume (PBV) map. PBV maps provide both qualitative (morphologic) and quantitative (hemodynamic) assessment of disease burden, combining information that would usually be gleaned separately from a V/Q scan and RHC. DECT can be an excellent tool to corroborate V/Q scan findings and accurately diagnose CTEPH.²⁴ The hemodynamic measurements derived from DECT also correlate well to those derived from RHC.²⁵ Establishing a role for DECT in CTEPH workup is a work in progress. While it is more commonly used in the UK, most US clinicians still rely on angiography.

Angiography and Right Heart Catheterization

The role of angiography in CTEPH workup is threefold: digital subtraction angiography, RHC, and LHC to detect incidental coronary artery disease. Occasionally, LHC may also reveal coronary-to-bronchial collateralization, but this is an incidental finding and does not affect management (Figure 4).

Digital subtraction angiography used to be the gold standard to diagnose and assess operability in CTEPH but has fallen out of favor with advancements and improvement in CT imaging. Additionally, CTPA is superior in detailing distal vascular anatomy and for operative planning. While RHC directly measures hemodynamic status, this can now be measured noninvasively with DECT. Despite the diminishing role of angiography in diagnosing CTEPH, it remains an important tool for treatment of CTEPH with balloon pulmonary angioplasty.

SURGICAL CANDIDACY

Pulmonary Thromboendarterectomy

Riociguat is the only drug that has been approved by the US Food and Drug Administration to improve pulmonary

blood flow and functional symptoms in CTEPH patients²⁶ and is an option for those who are not surgical candidates. However, the only curative treatment for CTEPH is pulmonary thromboendarterectomy (PTE), which surgically removes the chronic and organized thromboembolic lesions that are obstructing the pulmonary vasculature.

The survival benefit of PTE is estimated to be 90% and 75% at 3 and 10 years, respectively. With advances in surgical techniques, PTE can be performed more aggressively to tackle more complex and distal disease.²⁷ Despite PTE being potentially curative, the operation is performed only half as often in the United States compared with Europe²⁸ and often depends on patient preference. PTE is often overlooked as a treatment option due to lack of referral to an expert center that can offer the surgery.

PTE is a technically demanding procedure, but surgical outcomes are still strongly influenced by operable patient selection. Age is not a strict contraindication to PTE, with patients in their 70s and 80s achieving results comparable to younger patients.²⁹ The most important factors in assessing surgical risk are extent and location of chronic thromboembolic disease and degree of resultant pulmonary hemodynamic dysfunction. Other cardiac comorbidities are less impactful. Concomitant cardiac surgery for coronary artery and valvular heart disease can be performed safely without any added perioperative risk.³⁰

The only true contraindications to PTE are patients with concomitant parenchymal lung disease who typically benefit little from surgery. The improvement in perfusion may not effectively improve symptoms if ventilation is still severely compromised. These patients also face significant risk for respiratory failure after surgery.³¹

The decision to operate is still a gray zone and relies mainly on CTEPH team experience. Experienced centers have proposed that the potential benefit of PTE for CTEPH be extended to all patients, including those with distal disease.^{32,33} Candidacy for PTE remains a subjective decision, but a second opinion from another expert center can be helpful for borderline cases or cases deemed to be inoperable.

The most important factor to consider for PTE is the correlation of patient symptoms to the severity of PH, right heart failure, and extent of disease. The severity of PH and right ventricular dysfunction carry a more complicated postoperative course but should not be a hard exclusion for offering PTE. Thromboembolic disease in the proximal pulmonary vasculature (main, lobar, or segmental arteries) is more amenable to surgical approach and results in better perioperative outcomes. On the other hand, removal of distal disease seems to yield the most symptomatic

improvement. In the hands of the most experienced PTE surgeons, even distal disease can be approached surgically.³⁴

Additional complicating factors for PTE include patients with prior splenectomy and those with ventriculoatrial shunts, venous access catheters, or pacemaker leads. Like any other surgical procedure, patients with severe pulmonary disease, terminal illness, advanced malignancy, and frail status may also be at increased risk of operative morbidity and mortality. In the decision to operate, the CTEPH team should always consider what meaningful benefit is offered for the patient in terms of quality of life and survival advantage.²⁹

Surgical Technique

PTE is a technically demanding and complicated procedure. Bilateral pulmonary arteries are exposed and accessed through median sternotomy. Back bleeding from bronchial collaterals can obscure visibility, thus necessitating cardiopulmonary bypass and circulatory arrest to provide a clear, bloodless field during dissection (Figure 5). Cardiopulmonary bypass (CPB) is achieved through central aortic cannulation and bicaval venous cannulation. The venous bicaval cannula is inserted into the body of the atrium and directed into both cava (Figure 6). This allows for improved retraction of the superior vena cava and exposure of the right pulmonary artery. The dissection is done under deep hypothermic circulatory arrest for 15 to 20 minutes per side to achieve satisfactory removal of distal disease. During rewarming, any additional indicated concomitant cardiac surgery can be performed. CPB is resumed in between while closing the right atriotomy before starting the left side. At our institution, we start with the right side, resume circulation, and finish on the left side. The key to successful PTE is to identify the correct plane between thromboembolism and vessel.

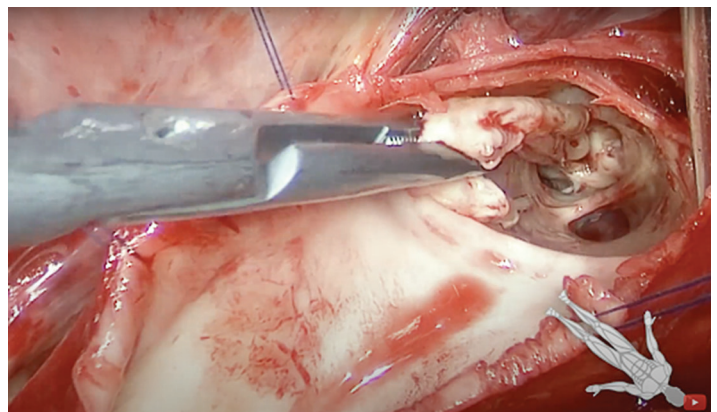


Figure 5. View from right pulmonary vasculature demonstrating the importance of a bloodless field to achieve complete distal dissection in pulmonary thromboendarterectomy.

Typically, it is the easiest plane to dissect and leaves behind a clear, white, smooth vessel (Figures 7, 8).

Details of the operation, instruments, and surgical classification of disease are detailed by Madani.³² Video presentation and walk through of the operation from our institution can be found online (Video 1).

Postoperative Care and Outcomes

PTE performed by an experienced team can be curative and fully restore hemodynamic function to baseline. Hemodynamic changes are usually immediate, but structural changes and remodeling are not. Data from the University of California San Diego and the International CTEPH registry show that PVR can drop up to 65% (PVR 700 to 800 $\text{dyn}\cdot\text{s}\cdot\text{cm}^{-5}$ to 250 $\text{dyn}\cdot\text{s}\cdot\text{cm}^{-5}$) and mean pulmonary arterial pressure (mPAP) to 43% (46 mm Hg to 26 mm Hg).³⁵ With return to normal hemodynamics, there is marked improvement in right heart function and tricuspid regurgitation. Clinically, great improvement can be seen in

New York Heart Association functional class, 6-minute walk distance, and quality of life.²⁸

Operative mortality from the University of California San Diego, the highest volume center in the United States, was < 2%. In addition, mortality rate was improved with increased case volume, even when adjusted for acceptance of high-risk PTE candidates. Unsurprisingly, mortality rate was directly proportional to degree of preoperative PVR. Preoperative PVR > 1,000 $\text{dyn}\cdot\text{s}\cdot\text{cm}^{-5}$ resulted in nearly four times the mortality rate than in patients with preoperative PVR < 1,000 $\text{dyn}\cdot\text{s}\cdot\text{cm}^{-5}$.³⁵

Reperfusion pulmonary edema (RPE) and coronary steal are the most common post-PTE complications. Clinically, RPE is characterized by persistent hypoxemia after initial improvement. In RPE, removal of chronic thromboembolism restores perfusion to the pulmonary arteries, reducing pulmonary resistance. This sudden plunge in pulmonary resistance, when lower than the rest of the patent pulmonary vasculature, can cause relative hyperperfusion of the endarterectomized vessels and “steal” from the previously

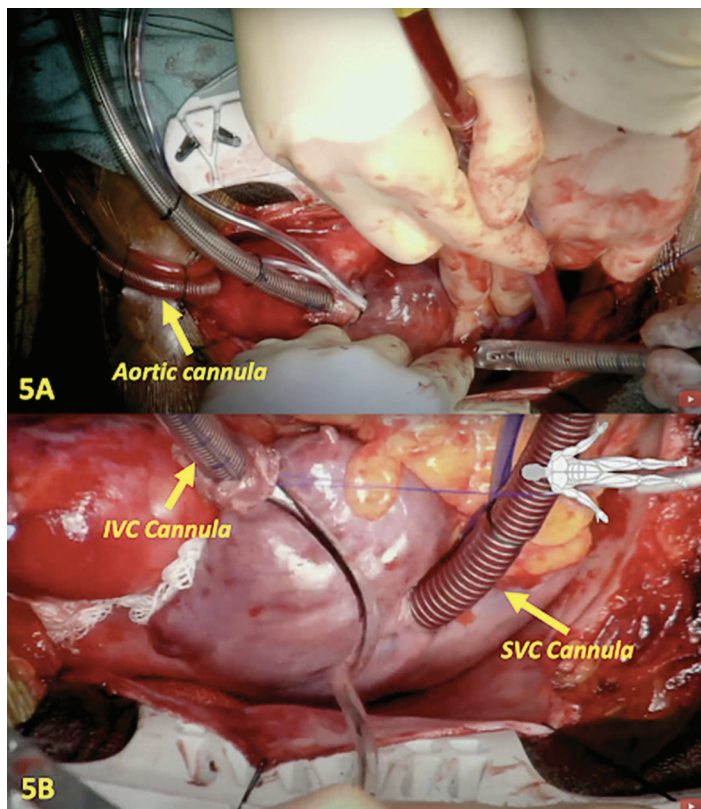


Figure 6.

(A) Central aortic cannulation for cardiopulmonary bypass. (B) Recommended configuration for bicaval venous cannulation (IVC/SVC) to facilitate mobilization of the SVC and exposure of the RPA medially. IVC: inferior vena cava; SVC: superior vena cava; RPA: right pulmonary artery

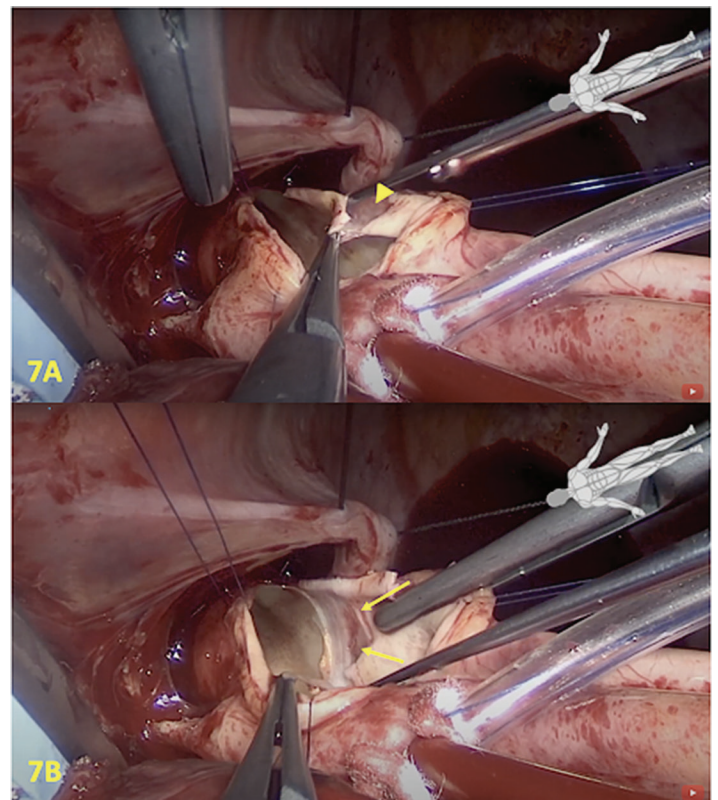


Figure 7.

(A) The correct dissection plane is white and smooth and often offers little resistance. (B) Yellow arrows indicate an incorrect plane of dissection, which appears pink.

normal perfused lung, as blood takes the path of least resistance³⁶; this can be detected by V/Q scan. This redistribution of flow usually resolves over weeks to months,³⁷ and thus treatment is supportive, with diuresis to reduce lung water and respiratory support. Severe RPE may be successfully treated with extracorporeal membrane oxygenation.^{38,39}

Reperfusion resulting in pulmonary infiltrate distal to the site of PTE is associated with higher morbidity and mortality.³⁴ The degree of arteriopathy on lung biopsy could be an important determinant in development of RPE post-PEA. Patients with residual PH have a tenfold mortality rate (10.3 vs 1%) compared to patients with no residual PH after PEA.³⁵ Additionally, low postoperative cardiac index with high mean PAP and PVR and are associated with reduced survival after PTE.⁴⁰

Persistent PH can be explained by incomplete PTE performed by an inexperienced surgeon or by residual distal small vessel disease, which cannot be resected surgically. Identifying the latter is important since residual macrovascular disease can be resolved with pulmonary angioplasty and microvascular disease can be improved with vasodilator therapy. Even with successful PTE, adequate anticoagulation is essential to prevent recurrent disease. Additional prospective studies are needed to determine the choice of anticoagulation for CTEPH; however, recent studies suggest that the choice of anticoagulant does not affect functional and hemodynamic post-PTE outcomes.⁴¹ Current guidelines advise CTEPH patients to receive anticoagulation for life. Vitamin K antagonists (coumadin) are most commonly used, but NOACs are increasingly being used with no safety issues. However, antiphospholipid syndrome is a contraindication to novel

oral anticoagulants.⁴² At our institution, we generally do not place perioperative inferior vena cava filters by default for PTE unless otherwise indicated. For more on this topic, see “Novel Treatment Pathways in Pulmonary Arterial Hypertension” by Tonelli and Qaiser in this issue.

Balloon Pulmonary Angioplasty

The role of balloon pulmonary angioplasty (BPA) in CTEPH treatment was first described in 2001 by Feinstein et al., who demonstrated improvement in mPAP and functional status post BPA in inoperable CTEPH patients. It fell from favor mainly due to high rates of post-BPA perfusion edema and high 30-day mortality rates.⁴³ In contrast to BPA, patients undergoing PTE show immediate improvement in mPAP and PVR, whereas hemodynamic improvement from BPA may not be seen for 3 months. With improved technology and experience at high volume centers, BPA is once again becoming a promising option for CTEPH treatment.^{44,45} BPA utilization remains a viable option to be discussed within the CTEPH team but is mainly helpful for patients with distal disease, severe hemodynamic lesions, unfavorable risk/benefit ratio, recurrent disease, prohibitive risk for PTE, or residual lesions after PTE. Its role continues to be studied, and its exact indication for CTEPH treatment remains controversial.

Unlike conventional angioplasty, BPA uses an undersized balloon over a wire to break lesions in the pulmonary arteries without disturbing the medial layers of the vessel. Pulmonary arteries are dilated after BPA, but this is not an immediate effect. BPA is performed in a staged, stepwise manner starting with smaller balloons, and the response in pulmonary artery size is re-evaluated before moving to a larger balloon. The optimal pressure ratio across each lesion is > 0.8 .⁴⁶ BPA sessions are divided into 3 to 10 sessions, each a week apart. This approach helps limit radiation exposure, fluoroscopy time, and contrast time. Additionally, spacing



Figure 8.

Specimen from a 37-year-old male with a history significant for antiphospholipid syndrome presenting with complete occlusion of right pulmonary artery, which appears mushroom-like (asterisk). Left pulmonary endarterectomy specimen shows an ulcerated lesion (arrow).

out BPA sessions was thought to reduce the incidence of reperfusion edema, but some centers have shown that multiple lobes can be tackled in a single session because the mechanism of reperfusion edema may be different for BPA versus PEA.^{44,47} Taken together, BPA can provide hemodynamic advantages for some patients prior to surgical PTE by reducing operative risks. BPA can also be used sequentially to tackle residual lesions and PH after PEA.⁴⁸ Thus, BPA can be a useful tool in hybrid surgical therapy for risky or refractory surgical candidates. It is important to note, however, that while these studies have demonstrated good outcomes for BPA, the outcomes have not yet been replicated in other countries. BPA should only be attempted at a CTEPH center of excellence with appropriate experience. PTE remains the gold standard for CTEPH treatment.

CONCLUSION

There are still many unresolved questions in the understanding, diagnosis, and treatment of CTEPH. First, the impact of pathobiology and PE-related risk factors on CTEPH progression is not fully understood. Furthermore, the role of newer imaging modalities (magnetic resonance angiography, DECT, optical coherence tomography) in CTEPH evaluation is still being established. Finally, there are no objective operability criteria for PEA, and the role of bridging medical therapy, BPA, and combination treatment strategy requires additional studies. For more on the topic of medical management, see “Chronic Thromboembolic Pulmonary Hypertension Medical Management” by Safdar and Logue in this issue.

CTEPH continues to be an underdiagnosed and undertreated sequelae of acute PE. Improving physician awareness about the incidence and treatability of this disease will help reduce rates of missed and delayed diagnosis. The most sensitive screening test is a V/Q scan, which should be followed up by RHC to assess hemodynamics. Finally, high-quality pulmonary angiography is required to confirm disease and assess operability.

All patients with CTEPH should be evaluated for potential PTE surgery by a specialized CTEPH team. All guidelines emphasize the importance of this evaluation because PTE surgery is the only potentially curative option for CTEPH in properly selected patients. Riociguat is the only medical treatment approved for CTEPH in patients deemed technically inoperable or with persistent PH after PTE. Finally, the role of BPA in treating CTEPH is still being defined. Although BPA shares some technical similarities to coronary and peripheral interventions, there are major differences in the type of specialist required, the nature of complications, and treatment goals. The role of BPA and its place amongst surgical and medical therapy is still being defined. This highlights the importance of an integrated, multidisciplinary approach with a dedicated CTEPH team to diagnose, treat, and follow up on CTEPH patients.

KEY POINTS

- All patients with thromboembolic pulmonary hypertension (CTEPH) should be evaluated for operability by an experienced CTEPH team since this diagnosis is often missed or delayed.
- Ventilation-perfusion scan is the best initial screening test, followed by right heart catheterization and pulmonary angiography, for diagnosis of CTEPH and operability assessment.
- Although pulmonary thromboendarterectomy (PTE) is a technically challenging operation, even when performed and managed at an experienced CTEPH center, it can dramatically cure or improve pulmonary hypertension.
- The role of balloon pulmonary angioplasty in CTEPH treatment is still being defined.
- Increased awareness of CTEPH, training in PTE surgery, and establishment of CTEPH teams will continue to benefit patients and improve CTEPH outcomes.

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Conflict of Interest Disclosure:

The authors have completed and submitted the *Methodist DeBakey Cardiovascular Journal* Conflict of Interest Statement and none were reported.

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