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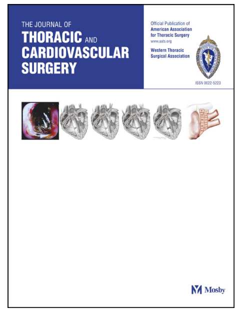

Repeat Pulmonary Thromboendarterectomy Outcomes: A 15 Year Single Center Retrospective Review

Anna Astashchanka, MD, Kim M. Kerr, MD, Jenny Z. Yang, MD, Angela Bautista, PA, Demosthenes G. Papamatheakis, MD, David S. Poch, MD, Nick H. Kim, MD, Victor G. Pretorius, MBchB, Michael M. Madani, MD, Timothy M. Fernandes, MD

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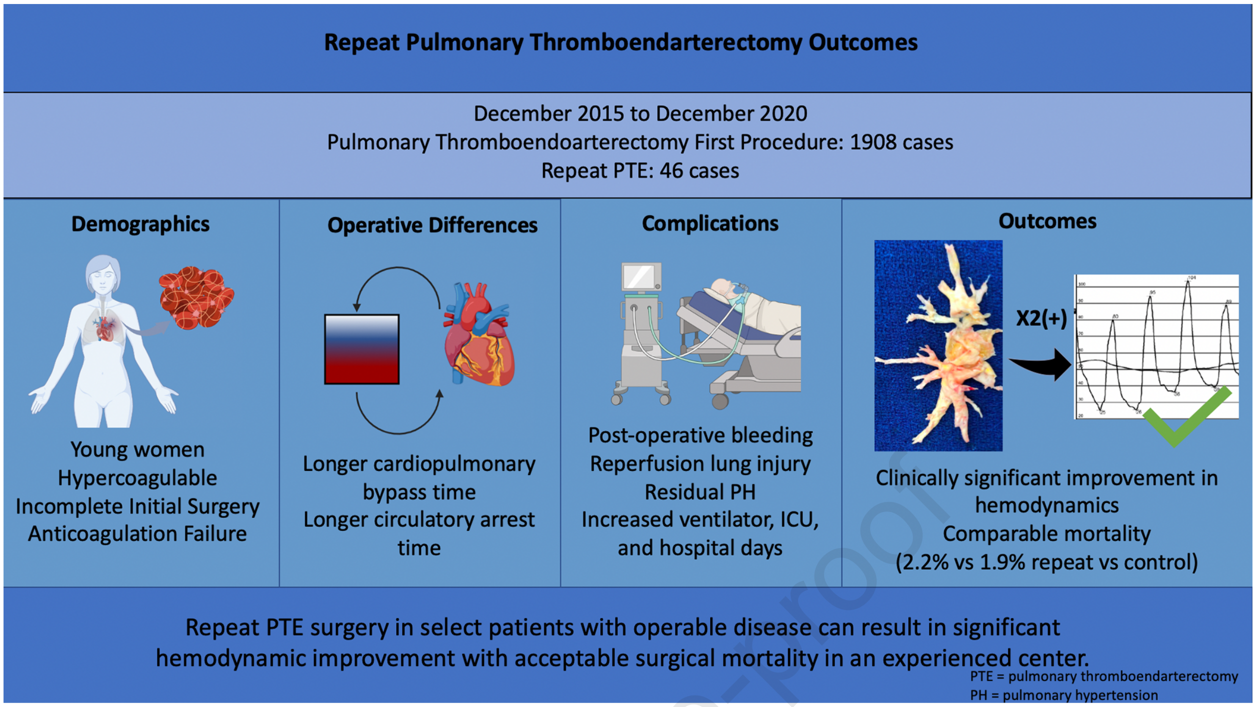
Repeat Pulmonary Thromboendarterectomy Outcomes
December 2015 to December 2020
Pulmonary Thromboendoarterectomy First Procedure: 1908 cases
Repeat PTE: 46 cases
Demographics
Young women
Hypercoagulable
Incomplete Initial Surgery
Anticoagulation Failure
Operative Differences
Longer cardiopulmonary bypass time
Longer circulatory arrest time
Complications
Post-operative bleeding
Reperfusion lung injury
Residual PH
Increased ventilator, ICU, and hospital days
Outcomes
X2(+)
Clinically significant improvement in hemodynamics
Comparable mortality
(2.2% vs 1.9% repeat vs control)
Repeat PTE surgery in select patients with operable disease can result in significant hemodynamic improvement with acceptable surgical mortality in an experienced center.
PTE = pulmonary thromboendarterectomy
PH = pulmonary hypertension

Title: Repeat Pulmonary Thromboendarterectomy Outcomes: A 15 Year Single Center Retrospective Review

Running Head: Repeat Pulmonary Thromboendarterectomy

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Word Count: 2658

Central Message:

In patients with recurrent CTEPH, repeat PTE carries increased risk of complications but results in significant hemodynamic improvement with comparable surgical mortality in an experienced center.

Perspective Statement:

This study demonstrates that repeat PTE may be an appropriate, safe and effective option in patients with CTEPH recurrence or incomplete initial PTE when performed at an experienced center. In addition, these findings may assist in risk-stratification and facilitate improved joint-decision making with patients regarding the risks and benefits of undergoing repeat PTE.

Legend for Central Picture:

Repeat PTE results in improved hemodynamics with comparable mortality to first-time PTE.

Glossary of Abbreviations

Abbreviation	Definition
CTEPH	Chronic thromboembolic pulmonary hypertension
PTE	Pulmonary Thromboendarterectomy
UCSD	University of California, San Diego
CVP	Central venous pressure
RAp	Right atrial pressure
mPAP	Mean pulmonary artery pressure
CO	Cardiac output
CI	Cardiac index
PVR	Pulmonary vascular resistance
TPR	Total pulmonary resistance
ICU	Intensive Care Unit
RV	Right Ventricle
VKA	Vitamin K antagonists
DOAC	Direct-Acting Oral Anticoagulants
NYHA	New York Heart Association
LMWH	Low Molecular Weight Heparin

Abstract:

Objective: Chronic thromboembolic pulmonary hypertension is potentially curable via pulmonary thromboendarterectomy. A minority of patients experience recurrence of their symptoms and are eligible for repeat pulmonary thromboendarterectomy. However, little data exists regarding risk factors and outcomes for this patient population.

Methods: We performed a retrospective review of the University of California San Diego chronic thromboembolic pulmonary hypertension quality improvement database, including all patients who underwent pulmonary thromboendarterectomy from December 2005 to December 2020. Of the 2,019 cases performed during this period, forty-six were repeat pulmonary thromboendarterectomy procedures. Demographics, pre- and post-operative hemodynamics and surgical complications were compared between the repeat pulmonary thromboendarterectomy group and 1,908 first pulmonary thromboendarterectomy group.

Results: Repeat pulmonary thromboendarterectomy recipients were more likely to be younger, have an identified hypercoagulable state and higher pre-operative right atrial pressure. Etiologies of recurrent disease include incomplete initial endarterectomy, discontinuation of anticoagulation (non-compliance or for medical reasons) and anticoagulation treatment failure. Repeat pulmonary thromboendarterectomy patients had significant hemodynamic improvement, but less pronounced compared to first pulmonary thromboendarterectomy patients. Repeat pulmonary thromboendarterectomy was associated with increased risk of post-operative bleeding, reperfusion lung injury, residual pulmonary hypertension, and increased ventilator, intensive care unit, and hospital days. However, hospital mortality was similar between groups (2.2% vs 1.9%).

Conclusion: This is the largest reported series of repeat pulmonary thromboendarterectomy surgery. Despite an increase in post-operative complications, this study demonstrates that repeat pulmonary thromboendarterectomy surgery can result in significant hemodynamic improvement with acceptable surgical mortality in an experienced center.

Word Count: 244

Keywords: pulmonary thromboendarterectomy, pulmonary endarterectomy, CTEPH, chronic pulmonary embolism

Introduction:

Chronic thromboembolic pulmonary hypertension (CTEPH) is a potentially curable form of pulmonary hypertension. CTEPH prevalence has been estimated as high as 38.4 per million inhabitants.[1] Prospective epidemiological data suggests that CTEPH incidence after acute, symptomatic pulmonary embolism can reach 4% with up to 2,500 new cases of CTEPH diagnosed in the United States each year.[2,,3] Pulmonary thromboendarterectomy (PTE) remains the treatment choice for patients with surgically accessible disease with superior hemodynamic outcomes, functional improvement, and survival compared to medical therapy alone[,4-8]. Despite surgical intervention, there have been reports of patients presenting with recurrent symptoms and new or residual surgically accessible disease. The etiology and risk factors of disease recurrence have not previously been described and the optimal treatment course for this patient population is unknown. Data regarding repeat PTE is limited to three small retrospective cohort studies with wide variability in rates of complications and mortality, including a reported mortality rate of 40% in one series[9-11,]. Based on this data, practitioners may defer referral for repeat PTE and focus on non-surgical management. With the emergence of alternate treatment regimens, efficacious medical therapy such as riociguat and expanding practice of balloon angioplasty (BPA), it is important to elucidate the true safety and efficacy of repeat PTE. This study was designed to describe the cause of recurrent thromboembolic disease in this patient population and to determine perioperative outcomes with repeat PTE surgery.

Materials and Methods:

We performed a retrospective review of the University of California San Diego (UCSD) CTEPH quality improvement database, including all patients (n= 2,019) who underwent pulmonary thromboendarterectomy between December 2005 to December 2020. Of the 2,019 procedures reviewed, 111 were identified as re-entry sternotomy procedures. Of those, 46 cases were identified as repeat PTE. Of note, two of the above identified cases were for a third PTE; thus, 44 unique patients had repeat PTE at UCSD with 46 total repeat PTE procedures. Results from second and third PTE procedures were recorded as separate cases. The 65 re-entry sternotomy cases not due to PTE were excluded from final analysis. Of note, of the 2,019 procedures, 157 were missing complete hemodynamics; hemodynamic data in these patients was excluded from final analysis, but other recorded variables including demographics and post-operative complications were included. Final analysis included 1,908 first PTE cases and 46 repeat PTE cases**. (Figure 1)**

Preoperative hemodynamics were obtained in both first PTE and repeat PTE groups prior to the procedure. Postoperative hemodynamics were obtained in the intensive care unit (ICU) prior to removal of the pulmonary artery catheter. Pulmonary vascular resistance (PVR) was estimated substituting the right atrial pressure for the pulmonary artery wedge pressure. Proximal vs. distal disease was determined by operative report with Jamieson Types and later standardized UCSD Classification Levels as previously described[12]. Proximal disease was defined as disease originating at the main, descending or lobar pulmonary artery (Level 1 or 2) in either left or right lung. Post-operative bleeding was defined as any early mediastinal bleeding requiring transfusion of blood products or return to operating room. Reperfusion injury was defined as evidence of new pulmonary opacity in an endarterectomized region and hypoxemia with no other explanation for the hypoxemia or opacity.

All hemodynamic variables are reported as mean ± standard deviation. Two-sided Fisher's exact test was performed for all categorical variables and two-tailed unpaired t-tests with p-value confirmation via the false discovery rate approach was performed for all continuous variables. Non-parametric Mann-Whitney testing was used to report ventilator days and ICU length of stay. Software used for statistics was GraphPad Prism version 8.00 for Windows (GraphPad Software, La Jolla California USA, www.graphpad.com). This study conducted utilizing an existing quality improvement database has been granted an exemption from the UCSD Institutional Review Board.

Results:

Patients undergoing repeat PTE were younger, more likely to have history of acute pulmonary embolism and an identified hypercoagulable state that those undergoing first PTE. The most common hypercoagulable state identified in repeat PTE patients was antiphospholipid syndrome, as determined by the presence of anti-cardiolipin, anti-beta-2 glycoprotein1 antibodies and/or lupus anticoagulant (n=19, 41.3%). In addition, repeat PTE patients were more likely to be on preoperative pulmonary hypertension targeted therapy (65.2% vs 48.2%, p=0.023). Preoperative right atrial pressures were higher in the repeat PTE group. Otherwise, preoperative hemodynamics did not statistically differ between the two groups. **(Table 1)** The median time between first and second PTE was 6 years [3;9] (range 1– 28 years) and 46% (21/46) of patients had their first PTE at UCSD.

Twelve patients (26%), all of which had their initial procedures at other centers, underwent repeat PTE to correct residual surgically accessible disease and symptomatic pulmonary hypertension, likely due to incomplete initial resection. Recurrent thrombosis was the indication for PTE in the remaining 34 patients. The most common cause of recurrent thrombosis were treatment failure (warfarin = 9, direct oral anticoagulant = 4 and low molecular weight heparin = 1).Anticoagulation non-compliance was documented in 11 patients (24%). Recurrent thrombosis occurred when anticoagulation was withheld for a medical indication (intracranial hemorrhage (n=2), pericardial effusion (n=1), hemoptysis (n=1)) or for other procedures (n=2; dental and orthopedic surgery). Three cases did not have a clear cause of recurrent thrombosis. (**Figure 2**) Postoperative hemodynamics were substantially improved in both cohorts. However, when compared to the first PTE group, repeat PTE patients had significantly higher post-operative mean pulmonary artery pressures, higher post-operative PVR, and total pulmonary resistance (TPR). Cardiopulmonary bypass time was significantly longer in the repeat PTE group compared to first PTE. Circulatory arrest time was longer in the repeat PTE group, but not statistically significant. (**Table 2**) Proximal disease was found in a similar percentage of first PTE and repeat PTE patients and the majority (75%) of those with an initial incomplete PTE were found to have proximal disease at the time of repeat PTE surgery.

Repeat PTE patients had higher median ventilator- , ICU- and postoperative hospital-days than the first PTE group. Repeat PTE patients were more likely to have post-operative bleeding complications, reperfusion lung injury, and residual pulmonary hypertension as defined by post-op PVR >400 dyn·s/cm5 compared to the first PTE group. Frequency returning to the operating room was not statistically different between the two groups. Patients requiring repeat PTE were more likely to be discharged with pulmonary hypertension targeted therapy. (**Table 3**) There was one in-hospital mortality (2.2%) among the 46 repeat PTE surgeries, which was not statistically significant compared to first PTE patients (1.9%, p=0.88). This subject died from refractory airway hemorrhage.

Comment:

This is the largest reported series of repeat pulmonary thromboendarterectomy. We found that repeat PTE may result in significant hemodynamic improvement and has comparable mortality when compared to those undergoing first PTE but is associated with increased complications. In the appropriate patient population, repeat PTE is feasible and safe when performed at an experienced center.

Pulmonary thromboendarterectomy is a technically challenging operation requiring cardiopulmonary bypass with profound hypothermia and periods of circulatory arrest for complete bilateral pulmonary endarterectomy. In repeat PTE surgery, the procedure is even more challenging not only due to considerations of redo-sternotomy in the setting of severe pulmonary hypertension and right heart hypertrophy, but also due to specific difficulties with establishing a plane of dissection within the pulmonary arteries. A team of multidisciplinary experts carefully reviews the history and course of the recurrent disease. **(Figure 3)** Typically, whenever possible, we would like to wait more than 6 months from the first operation before performing a repeat PTE. As part of the assessment for repeat PTE, the adequacy of the initial PTE is reviewed, including evaluation of the specimen retrieved, the degree of reperfusion post initial surgery and initial hemodynamic. Those with unfavorable outcomes after initial surgery with adequate specimen retrieval would not likely benefit from repeat PTE. The characteristics of the residual/recurrent disease are also evaluated, including the surgical proximity, degree of clot and whether current clot burden can appropriately explain their pulmonary hemodynamics. Those with a small clot burden but severe pulmonary hypertension are not likely to benefit from repeat intervention. There are no absolute contraindications to repeat surgery, although relative contraindications may include a poorly tolerated initial PTE, prior history of post-operative thrombosis despite anticoagulation or significant post-operative lung injury. In addition to the usual pre-operative evaluation and work-up, review of an updated CT scan of the chest to identify mediastinal landmarks and anticipated challenges of redo-sternotomy in the setting of right ventricular hypertension and hypertrophy is crucial. With careful pre-operative planning and meticulous redo-sternotomy techniques, chances of cardiac injury are low – notably, no patients suffered from cardiac injury intra-operatively in this cohort.

All patients have intraoperative femoral arterial and venous access lines placed prior to sternotomy for possible immediate need of percutaneous initiation of cardiopulmonary bypass, although this is rarely needed. Once sternotomy is completed, the goal is to identify and clear the adhesions over the ascending aorta and the right atrium to initiate full bypass and decompress the heart. Once this is performed, further take down of adhesions can be performed during the cooling phase. The procedure then continues in a similar fashion to a first time PTE, although cardiopulmonary bypass time may be longer in this patient population. The endarterectomy portion of the procedure can be more complex in repeat PTE. In patients with inadequate or incomplete first operation, the endarterectomy plane is undisturbed and full PTE can be performed without any further challenge. However, in patients with prior complete endarterectomy and true recurrent disease, the new plane of dissection is typically deeper, more scarred, and more challenging to remove. It is not unusual to have to enter the plane of media so that endarterectomy can be performed. The challenges of identifying a new plane, and completing full endarterectomy in these patients explain the longer cardiopulmonary bypass and circulatory arrest times.

More than a quarter of repeat PTE patients underwent first PTE at an another center and, on evaluation at our center, were noted to have incomplete initial PTE. Notably, 75% of these patients were found to have proximal CTEPH at the time of their repeat procedure. This reaffirms the current recommendation that operability assessment and surgery should be performed at an experienced CTEPH center.[4, 5]. Surgical candidacy and operability assessment remains subjective based on experience and controversial, differing from center to center. Those with residual pulmonary hypertension after PTE may benefit from evaluation at an expert center to determine repeat procedure candidacy.

Anticoagulation non-compliance and anticoagulation failure accounts for the majority of recurrent CTEPH in the evaluated cohort. Lifelong anticoagulation is recommended after PTE for all patients, and vitamin K antagonists (VKAs) traditionally have been the recommended antithrombotic for both individuals with CTEPH and those with antiphospholipid syndrome.[12,13] The risks and benefits of vitamin K antagonists vs. direct-acting oral anticoagulants (DOACs) in the CTEPH population is limited to retrospective case series at this time. One evaluation of 501 CTEPH patients did not demonstrate any significant difference in efficacy of DOACs vs warfarin with respect to recurrent thromboembolism, [14] while a retrospective review of 1000 post-PTE patients demonstrated a disproportionately higher incidence of thromboembolism recurrence in those using DOACs vs. warfarin (4.62%/person-year for DOACs vs 0.76%/person-year for VKAs, p=0.008).[14,15] In addition, a recent abstract reports that CTEPH patients referred for PTE on DOAC therapy were twice as likely to have associated acute or subacute thrombi intra-operatively.[16] Additional research is needed to determine the safety and efficacy of DOACs in this patient population, but may be an important factor in enhancing patient compliance and preventing thrombosis reoccurrence.

Residual pulmonary hypertension post PTE is relatively common, and has been reported in 25-31% of patients, depending upon the center and definition used.[17-19] In our cohort, residual pulmonary hypertension as we defined by a PVR > 400 dynes.sec.cm-5 on early postoperative hemodynamics, was significantly more common in the repeat PTE population (35.0%) than in the first PTE population (11.8%). In addition, although our study also found significant hemodynamic improvement, repeat PTE patients were more likely to be discharged from the hospital on pulmonary hypertension targeted therapy and oxygen than the first PTE group. Our findings are consistent with previous publications by Mo et al.[11] and Merli et al.[10] who also found patients undergoing repeat PTE had less pronounced improvement in their mPAP, PVR and TPR than those undergoing first time PTE. Despite this, the prior series demonstrated repeat PTE resulted in statistically significant improvement in their degree of pulmonary hypertension and symptoms as assessed by NYHA functional class.[10]

Balloon pulmonary angioplasty (BPA) has become an established treatment option for inoperable CTEPH, with multiple studies demonstrating improvement in hemodynamics, functional class/exercise capacity, and quality of life with BPA[20-23]. This has led to a growing role for BPA in patients with residual pulmonary hypertension after PTE.[24-26] Many post-PTE patients who remain symptomatic may not be eligible for a repeat PTE due to the distal nature of the residual chronic thromboembolic disease. At our institution, approximately 20-25% of our BPA cohort are post-PTE; additionally, of our post-PTE BPA patients, 94% had their PTE performed at UCSD[24]. However, if there was an incomplete endarterectomy or recurrent thrombosis leading to new proximal occlusions, these patients may benefit from redo PTE instead as BPA may be less effective for proximal lesions and complete occlusions.

As demonstrated in prior studies evaluating repeat PTE, those undergoing repeat surgical intervention were more likely to have post-operative complications. However, unlike previous studies, repeat PTE in our current study was not associated with increased hospital mortality. In contrast to the original cohort study by Mo et al.[11], reperfusion lung injury was more common in our cohort of repeat PTE patients compared to first-time PTE cases. Reperfusion lung injury (RPE) typically occurs within 48 hours of revascularization and presents with hypoxemia and radiographic infiltrates in areas re-perfused with surgery.[18] Severity of preoperative pulmonary hypertension and the presence of residual pulmonary hypertension have been associated with an increased risk of RPE.[20] Postoperative complications, including increase in postoperative bleeding as well as reperfusion injury are likely the source of the overall increase in the median ventilator days, ICU length of stay, and post-operative length of stay. While mortality does not appear to be affected, the increased morbidity can add significant cost burden to the patient.

This study has several limitations. The UCSD CTEPH Quality Improvement Database requires significant retrospective review, and some factors that have been progressively found to be important in CTEPH, including echocardiogram measurements, metabolic markers, or type of anticoagulant and adherence were not always recorded. Outcomes in the repeat PTE group may be confounded by selection bias, as the individuals that underwent repeat PTE were deemed by a multi-disciplinary team to be optimal surgical candidates. Thus, their outcomes may not necessarily apply to all individuals with recurrent CTEPH. Due to the high degree of variance in the first PTE group, conclusions regarding post-operative complications cannot be directly attributed to repeat-PTE status without controlling for multiple potential confounders.

In addition, since UCSD is a tertiary referral center, patients are often lost to follow up after completing surgical intervention. Because of this, long-term outcomes, including follow-up hemodynamics, symptoms, use of pulmonary hypertension medications, healthcare utilization, as well as mortality are not readily available. Moreover, surgical outcomes may not be generalizable to less experienced centers.

In this large single center series from an experienced CTEPH center, repeat PTE in select patients resulted in significant hemodynamic improvement with a low mortality, but increased post-operative complications, ventilator, ICU and hospital days. (Figure 4) This provides clarification regarding true surgical risk and supports referral for PTE, even if a patient has undergone prior PTE. In addition, this study illuminates potential causes of recurrent CTEPH including hypercoagulable state and anticoagulation failure, but human factors, including anticoagulation compliance, contribute significantly to recurrence. Finally, it is prudent to note that up to 25% of cases are due to inadequate resection during their first PTE, highlighting the importance of undergoing the evaluation and initial procedure at experienced, high volume centers to avoid possible additional surgical morbidity and mortality.

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Table 1: Baseline Characteristics and Pre-Operative Hemodynamics

	First PTE n=1908	Repeat PTE n=46	p value
Age (years)	53.2 ± 15.2	42.9 ± 14.5	<0.001[a]
Female	48%	61%	0.077
BMI (kg/m2)	30.5 ± 7.4	30.0 ± 8.2	0.713
History of pulmonary embolism	90.5%	100%	0.028[a]
Known hypercoagulable state	34.1%	54.3%	0.003[a]
PH targeted therapy	48.2%	65.2%	0.023[a]
Right atrial pressure (mmHg)	10.0 ± 5.7	13.1 ± 6.9	0.006[a]
Mean pulmonary artery pressure (mmHg)	41.8 ± 13.2	43.7 ± 12.4	0.347
Cardiac output (L/min)	4.7 ± 1.38	4.3 ±1.4	0.100
Cardiac Index (L/min/m2)	2.30 ± 0.61	2.26 ± 0.56	0.670
Pulmonary vascular resistance (dyn·s/cm^5)	613 ± 363	707 ± 455	0.184
Total pulmonary resistance (dyn·s/cm^5)	823 ± 410	956 ± 480	0.077

BMI=body mass index, PH targeted therapy = patients on any of the following preoperatively: riociguat, endothelin receptor antagonist, PDE-5 inhibitor, prostacyclin, PTE = pulmonary thromboendarterectomy [a]

$p < 0.05$ statistically significant.

Table 2: Early Postoperative Hemodynamics and Intraoperative Data

	First PTE n=1908	Repeat PTE n=46	p value
CVP (mmHg)	9.70 ± 5.3	11.1 ± 4.3	0.076
Mean pulmonary artery pressure (mmHg)	23.8 ± 7.5	31.7 ±9.6	<0.001[a]
Cardiac output (L/min)	5.6 ± 1.31	5.4 ± 1.2	0.150
Cardiac index (L/min/m2)	2.8 ± 0.52	2.9 ± 0.63	0.560
Pulmonary vascular resistance (dyn·s/cm^{-5})	234 ± 119	337 ± 170	<0.001[a]
Total pulmonary resistance (dyn·s/cm^{-5})	359 ± 149	500 ± 209	<0.001[a]
Patients with proximal disease (%)	71.8%	78.3%	0.335
Circulatory Arrest Time (min)	46.0 ± 18.1	48.5 ± 19.3	0.402
Cardiopulmonary bypass time (min)	258 ± 86.0	283 +44.5	<0.001[a]
Concomitant Procedure (PFO/valve/CABG) CABG Valve PFO	21.6% (159/1908) 8.3% (53/1908) 2.8% (408/1908) 21.1%	23.9% (0/46) 0% (4/46) 8.7% (6/46) 13.0%	0.700

CABG=coronary artery bypass graft ,CVP=central venous pressure, PFO=patent foramen ovale

PTE=pulmonary thromboendarterectomy

[a] $p < 0.05$ statistically significant.

Table 3: Post-operative Outcomes

	First PTE n=1908	Repeat PTE n=46	p value
In-hospital Mortality	1.9%	2.2%	0.888
Ventilator Days (Range)	1.0 [1;2] (1-70)	1.5 [1;4] (1-12)	0.024[a]
ICU LOS (Days) (Range)	4 [2;6] (1-94)	5 [3;7] (2-39)	0.025[a]
Postop LOS (Days) (Range)	8 [3;7] (5-121)	12 [10;16] (6-40)	0.034 [a]
Return to Operating Room	4.6%	7.0%	0.401
Bleeding	11.8%	35.0%	<0.001[a]
Requirement of blood products	5.2%	20.0%	<0.001 [a]
Reperfusion Lung Injury	17.2%	32.6%	0.013[a]
Re-intubation	3.3%	7.0%	0.747
ECMO	0.94%	0.0%	N/A
Atrial arrhythmia	23.7%	11.6%	0.032[a]
Pneumonia	9.8%	7.0%	0.558
PH-targeted Medication on Discharge	3.11%	36.1%	<0.001[a]
Residual PH	11.8%	35.0%	<0.001[a]

Continuous data presented as median [first;third quartiles] LOS = length of stay, PH = pulmonary hypertension, Residual PH = early postoperative pulmonary vascular resistance > 400 dynes.sec.cm-^{5}

[a]p<0.05 statistically significant

Figure Legends

Figure 1: Distribution of cases including all PTEs performed between December 2005 and December 2020. Patients who had a prior sternotomy for surgery other than PTE were excluded from the analysis.

PTE=pulmonary thromboendarterectomy

Figure 2: Etiology of recurrent or residual CTEPH

DOAC = Direct oral anticoagulant, LMWH=low molecular weight heparin

PTE=pulmonary thromboendarterectomy

Figure 3: Flowchart detailing components of patient selection for repeat PTE

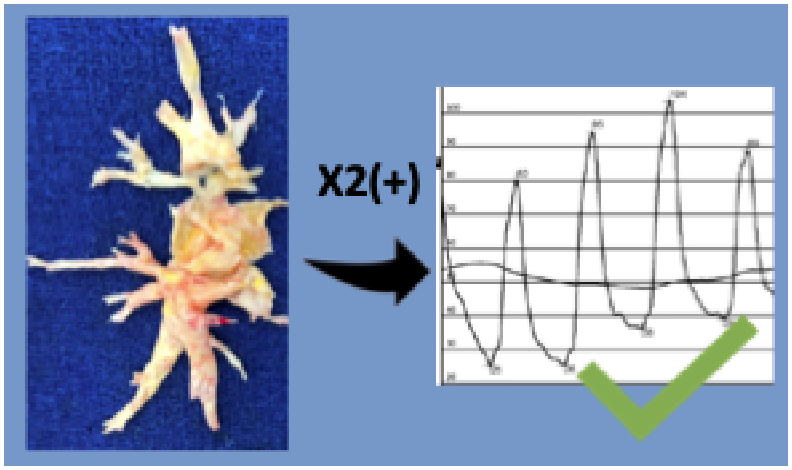
PTE=pulmonary thromboendarterectomy, HD=pulmonary hemodynamics

Figure 4: Summary of pertinent findings on evaluation of 46 repeat pulmonary thromboendoarterectomy cases.

PH= pulmonary hypertension, PTE = pulmonary thromboendarterectomy

Supplementary Figure 1: pre- and post-opertaive mean pulmonary artery pressures (a) and pulmonary vascular resistance (b) in 24 patients for their first and second PTE.

Supplementary figure 2: Cardiopulmonary bypass times and circulatory arrest times for 24 patients for their first and second PTE.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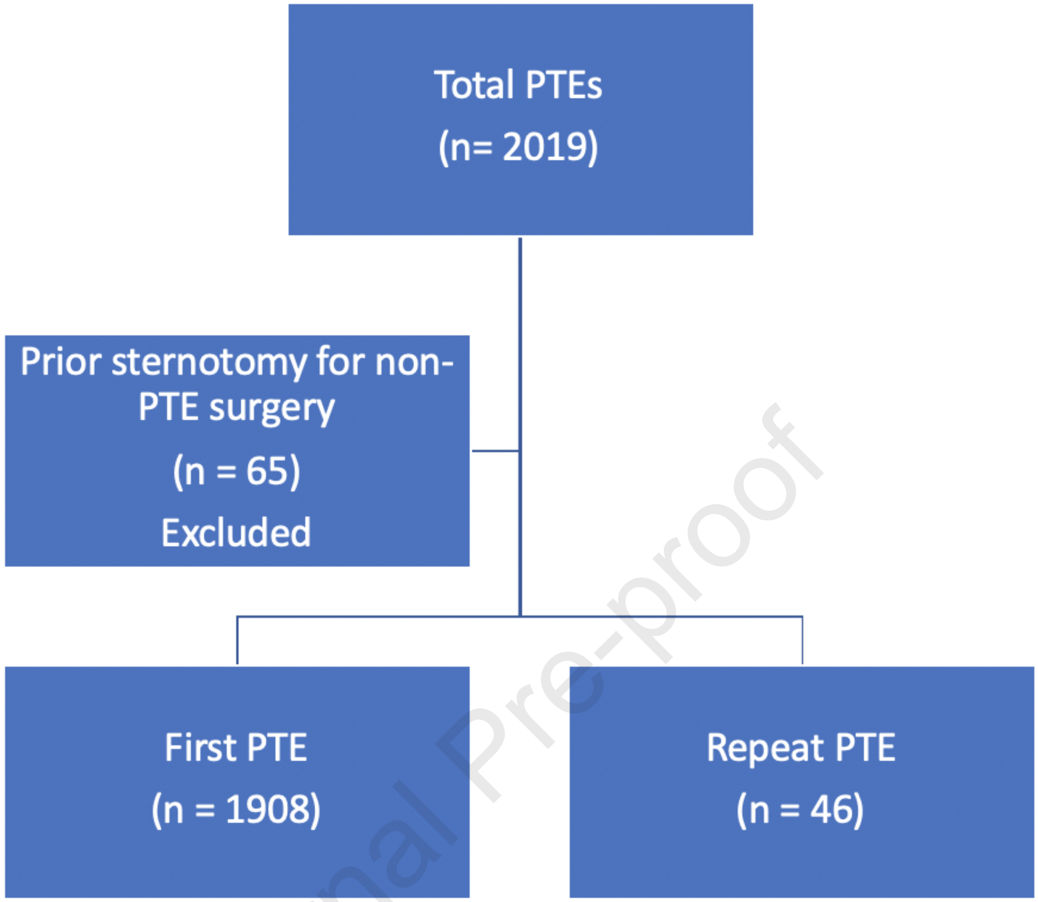
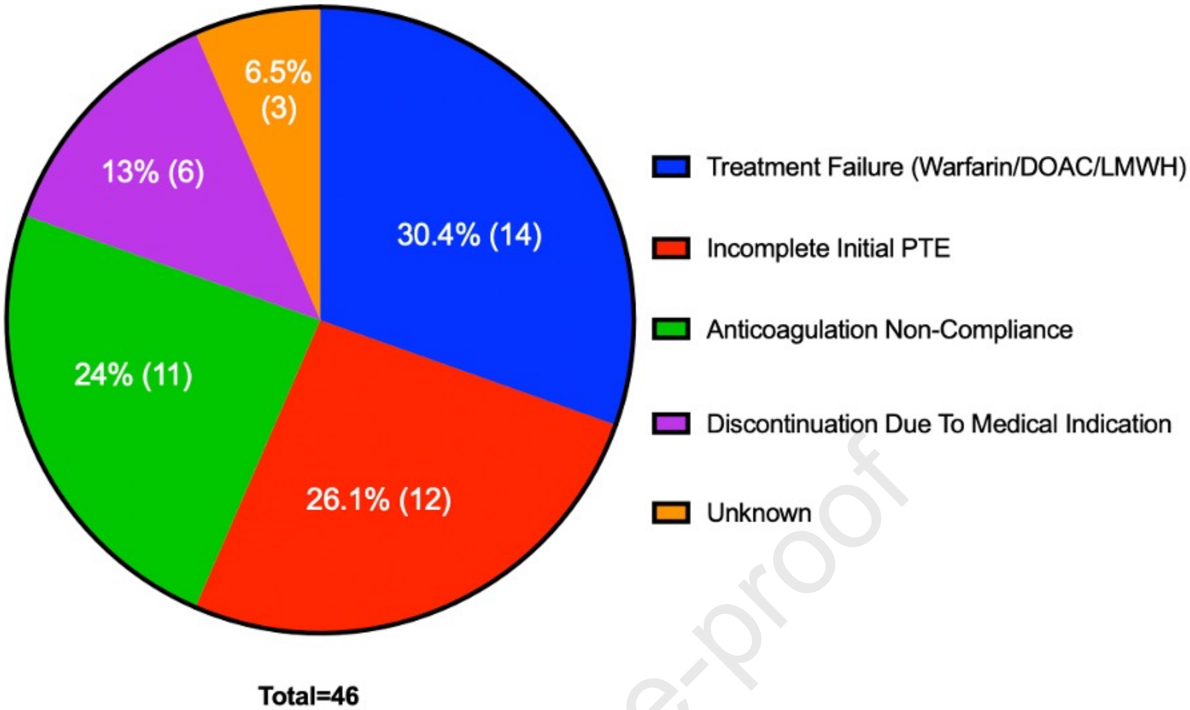
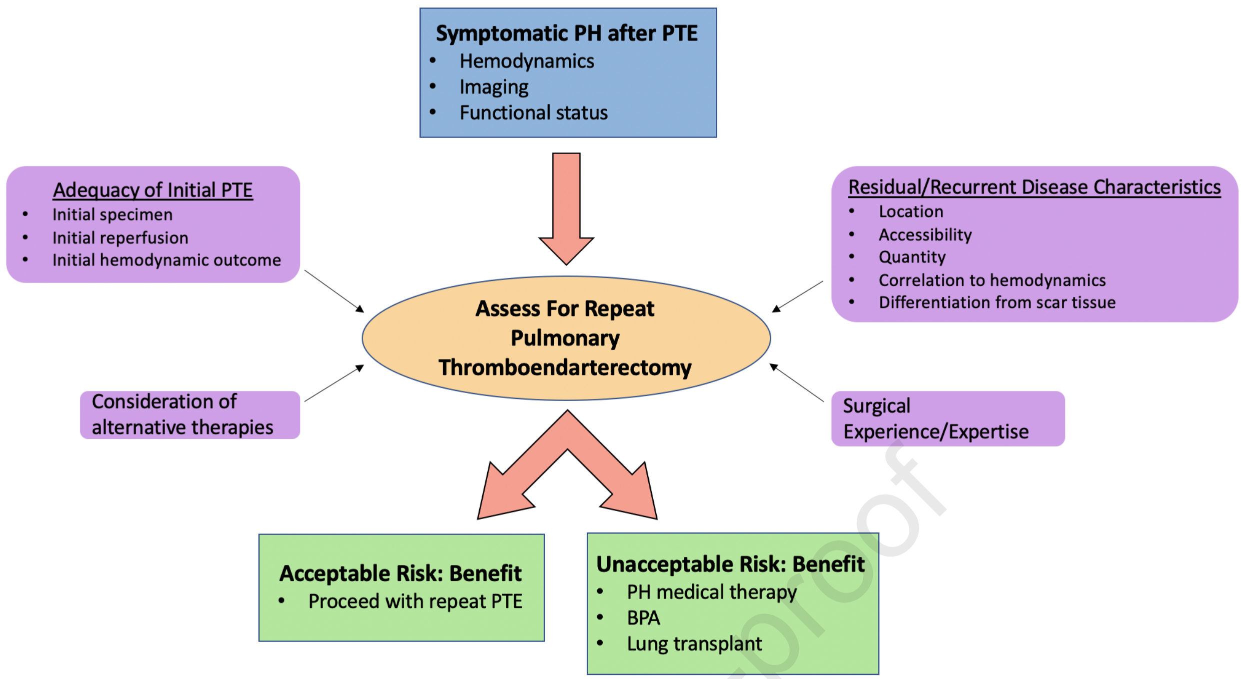

Total PTEs
(n= 2019)
Prior sternotomy for non-PTE surgery
(n = 65)
Excluded
First PTE
(n = 1908)
Repeat PTE
(n = 46)

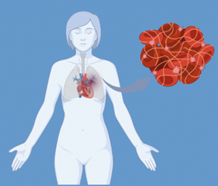

6.5% (3)
13% (6)
30.4% (14)
24% (11)
26.1% (12)
Treatment Failure (Warfarin/DOAC/LMWH)
Incomplete Initial PTE
Anticoagulation Non-Compliance
Discontinuation Due To Medical Indication
Unknown
Total=46


Symptomatic PH after PTE
• Hemodynamics
• Imaging
• Functional status
Adequacy of Initial PTE
• Initial specimen
• Initial reperfusion
• Initial hemodynamic outcome
Residual/Recurrent Disease Characteristics
• Location
• Accessibility
• Quantity
• Correlation to hemodynamics
• Differentiation from scar tissue
Assess For Repeat Pulmonary Thromboendarterectomy
Consideration of alternative therapies
Surgical Experience/Expertise
Acceptable Risk: Benefit
• Proceed with repeat PTE
Unacceptable Risk: Benefit
• PH medical therapy
• BPA
• Lung transplant

Repeat Pulmonary Thromboendarterectomy Outcomes

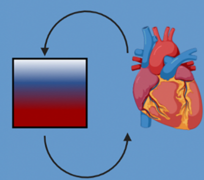
December 2015 to December 2020
Pulmonary Thromboendoarterectomy First Procedure: 1908 cases
Repeat PTE: 46 cases

Demographics



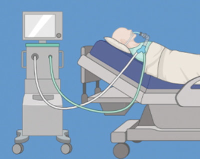
Young women
Hypercoagulable
Incomplete Initial Surgery
Anticoagulation Failure

Operative Differences



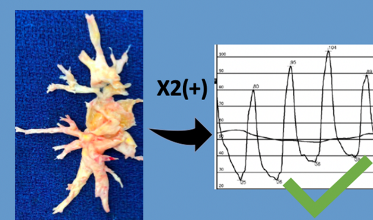
Longer cardiopulmonary bypass time
Longer circulatory arrest time

Complications



Post-operative bleeding
Reperfusion lung injury
Residual PH
Increased ventilator, ICU, and hospital days

Outcomes



Clinically significant improvement in hemodynamics
Comparable mortality
(2.2% vs 1.9% repeat vs control)

Repeat PTE surgery in select patients with operable disease can result in significant hemodynamic improvement with acceptable surgical mortality in an experienced center.

PTE = pulmonary thromboendarterectomy
PH = pulmonary hypertension

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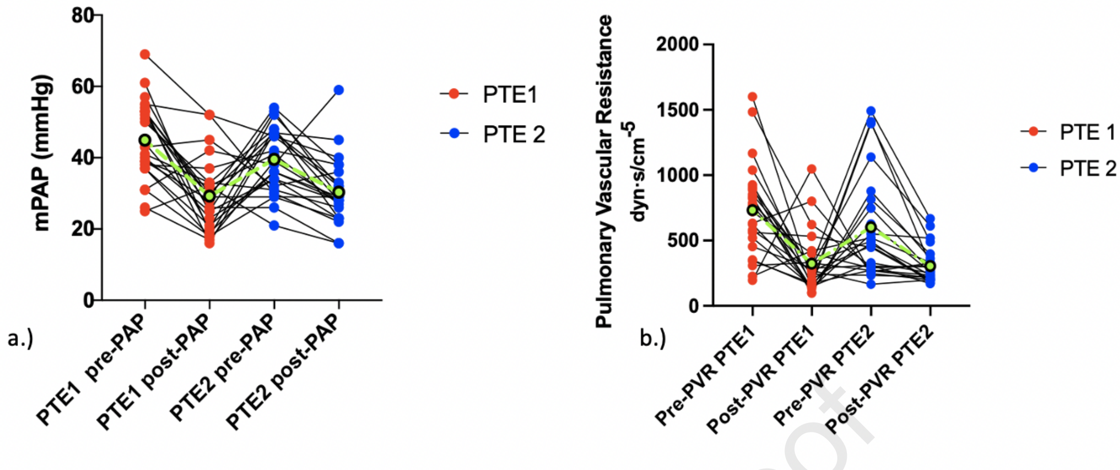
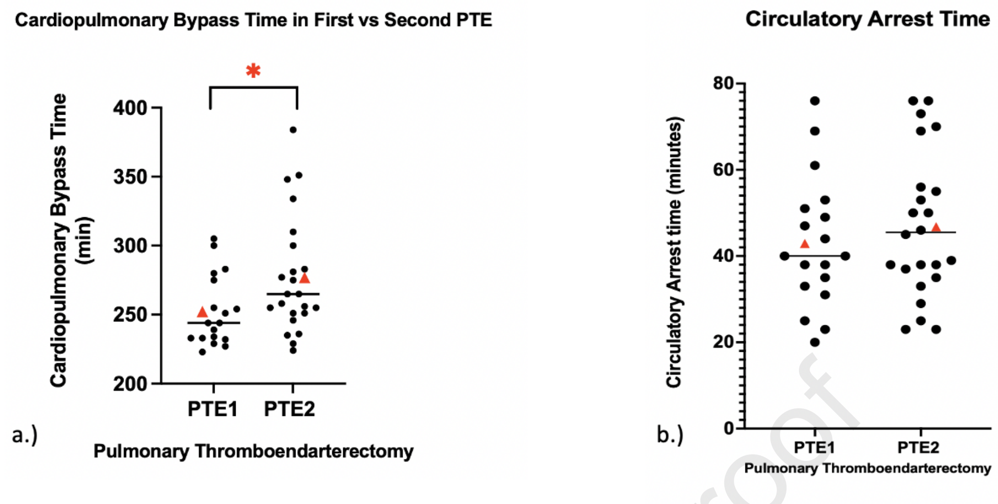
Supplementary Figure 1



Supplementary Figure 1: Pre- and post-operative mean pulmonary artery pressures (a) and pulmonary vascular resistance (b) in 24 patients for their first and second PTE.

= average value

Supplementary Figure 2



Supplementary Figure 2: Cardiopulmonary bypass times and circulatory arrest times of 24 patients for Their first and second PTE.

*: $p<0.005$ ▲ = average value

Supplementary Table 1

First PTE vs Repeat PTE Internal Comparison (24 Patients)

	First PTE	Repeat PTE (n=24)	P value
Years Between PTE (Range)	6 [3;9] (1-28)		
Pre-operative Mean pulmonary artery pressure (mmHg)	45.0	40.0	P=0.08
Pre – Operative Pulmonary vascular resistance (dyn·s/cm^{-5})	733	603	P=0.24
Post - operative Mean pulmonary artery pressure (mmHg)	29.3	30.3	P=0.70
Post – Operative Pulmonary vascular resistance (dyn·s/cm^{-5})	324	304	P=0.73
Cardiopulmonary bypass time	252	276	P=0.04
Circulatory arrest time	42.0	46.0	P=0.45

Continuous data presented as median [first;third quartiles] LOS = length of stay, PH = pulmonary hypertension, Residual PH = postoperative pulmonary vascular resistance > 400 dynes.sec.cm-^{5}

$^{a}p<0.05$ statistically significant