Role of a multidisciplinary team approach in the management of chronic thromboembolic pulmonary hypertension

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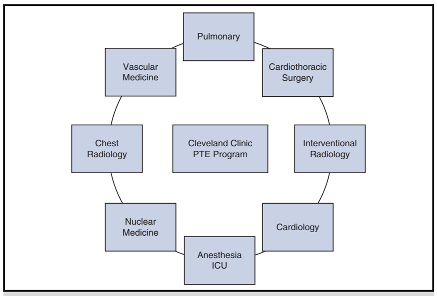
ABSTRACT

Objective: Chronic thromboembolic pulmonary hypertension (CTEPH) is an under-recognized complication of pulmonary embolism that, if left untreated, leads to heart failure. This study aimed to characterize the role of a multidisciplinary team in the management of CTEPH.

Methods: Starting in 2011, a multidisciplinary team was assembled to systematically evaluate and manage all CTEPH patients based on hemodynamic profile, extent of thromboembolic disease burden, and comorbidities. From 1997 to 2021, 306 patients underwent pulmonary thromboendarterectomy for CTEPH. The cohort was divided into an early era prior to 2011 (62 cases) and a recent era from 20,211 to 2021 (244 cases).

Results: Baseline demographic and hemodynamic profiles were similar in the 2 eras, with a mean age of 53 ± 14 years, mean pulmonary artery pressure of 44.9 ± 11.2 mm Hg, and mean pulmonary vascular resistance of 7.4 ± 3.9 Wood units. Early era patients had more severe right ventricular dysfunction (49.1% vs 25.0%; $P < .001$). Recent era patients underwent more concomitant tricuspid valve repairs (22% vs 2.9%; $P < .001$) despite similar tricuspid regurgitation severity. Following surgery, recent era patients had lower in-hospital mortality (2.9% vs 12%) with less morbidity, including less prolonged ventilation (32% vs 59%), less need for dialysis (1.6% vs 21%), and shorter hospital length of stay (16 days vs 21 days). The difference in survival was sustained long-term (88% vs 70% at 6 years).

Conclusions: Outcomes after pulmonary thromboendarterectomy improved since the establishment of the multidisciplinary team—most notably, more complete resolution of pulmonary hypertension and improved overall survival. A team-based approach for selection and perioperative management of these complex patients can be associated with improved early outcomes. (JTCVS Open 2025;24:147-55)



Cleveland Clinic's multidisciplinary CTEPH team model

CENTRAL MESSAGE

A team-based approach to caring for patients with chronic thromboembolic pulmonary hypertension can lead to improved outcomes after pulmonary thromboendarterectomy, with longer overall survival and more complete resolution of pulmonary hypertension.

PERSPECTIVE

Pulmonary thromboendarterectomy is an effective treatment for chronic thromboembolic pulmonary hypertension (CTEPH) but requires careful patient selection. Our study characterizes the role of a multidisciplinary team in the development and growth of a CTEPH program. We find that in combination with growing surgical expertise, implementing multidisciplinary approach to tailoring the optimal therapy for appropriate patients can be associated with early outcomes.

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This study was approved by the Cleveland Clinic Institutional Review Board (IRB 8097; approved April 15, 2022). Informed consent was waived given the retrospective nature of this study.

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Abbreviations and Acronyms

BMI = body mass index
CTEPH = chronic thromboembolic pulmonary hypertension
PTE = pulmonary thromboendarterectomy
PVR = pulmonary vascular resistance
mPAP = mean pulmonary artery pressure
RHC = right heart catheterization
RV = right ventricular
TVr = tricuspid valve repair
V/Q = ventilation-perfusion

Chronic thromboembolic pulmonary hypertension (CTEPH) is an under-recognized complication of acute pulmonary embolism[1-3] characterized by impaired fibrinolysis, incomplete thrombus resolution, and vascular remodeling, leading to pulmonary hypertension, right heart dysfunction, and, if left untreated, decreased life expectancy.[4-8] Pulmonary thromboendarterectomy (PTE) is standard of care and offers the best chance of cure in appropriately selected patients[9-11]; however, the operation is technically challenging and is performed mostly at a few high-volume centers.[12,13] A multidisciplinary team approach to CTEPH management may allow for proper patient selection, which can lead to improved early outcomes following PTE. In this single-center study, we analyzed our outcomes of PTE surgery before and after implementation of the CTEPH multidisciplinary team approach.

METHODS

Study Design and Patient Selection

All adult patients undergoing PTE for CTEPH at our center between January 1, 1997, and January 1, 2022, were reviewed retrospectively. In January 2011, a multidisciplinary CTEPH team was assembled to discuss and review all CTEPH cases. The team met weekly and consisted of dedicated specialists, including cardiothoracic surgeons, pulmonary hypertension specialists, interventional radiologists, vascular medicine specialists (Figure 1, *A*). The goal of multidisciplinary team discussion is to ensure correct CTEPH diagnosis and to tailor the optimal therapy for each patient, including PTE surgery, endovascular intervention, and/or medical therapy. The cohort was divided into 2 groups for analysis: prior to CTEPH team institution (pre-2011; early era) and after CTEPH team institution (post-2011; recent era).

Standard testing for CTEPH includes echocardiography, ventilation-perfusion (V/Q) scintigraphy, computed tomography pulmonary angiography and/or conventional pulmonary angiography pulmonary function testing, and right heart catheterization. CTEPH diagnosis was based on the presence of perfusion defects on V/Q scan with anatomic evidence of chronic thromboembolic disease on pulmonary angiography[5] and precapillary pulmonary hypertension, defined as a mean pulmonary artery pressure (mPAP) of ≥25 mm Hg and pulmonary vascular resistance (PVR) of ≥3 Wood units. In addition, patient selection for PTE was determined based on the degree of symptoms, PVR, and right ventricular (RV) dysfunction balanced against such risk factors as advanced age, multiple morbidities, and poor operative fitness. Before establishment of the multidisciplinary CTEPH team, these tests were interpreted independently by referring physicians and reviewed by the surgeon prior to PTE.

Surgical Technique

A detailed description of the surgical technique for pulmonary thromboendarterectomy has been published recently.[14] In brief, the pulmonary arteries are accessed via a median sternotomy. Cardiopulmonary bypass (CPB) and systemic cooling are initiated via ascending aorta and bicaval cannulation, and the heart is vented via the main pulmonary artery and left ventricle. Once the patient has been cooled to 18°C, circulatory arrest is initiated. Left pulmonary arteriotomy is performed longitudinally to the level of the pericardium. The heart is retracted to the right side using a HeartNet (DMC Medical) to maximize visualization. An endarterectomy plane is created and carried out distally to the level of the segmental and subsegmental arteries, with careful attention to the correct plane between the intima and media. After completion of endarterectomy on the left side, the patient is reperfused while the arteriotomy is closed. Reperfusion is allowed for 10 minutes before circulatory arrest is reinstituted. A longitudinal incision is then made in the right pulmonary artery. Circulatory arrest is again reinstituted, and endarterectomy is performed in a similar manner as for the left side. The duration of circulatory arrest on each side is limited to 20 minutes. After completion of endarterectomy, the patient is reperfused and warmed. Any concurrent cardiac procedures are typically performed at this time. The heart is deaired, and the patient is weaned from CPB following acceptable hemodynamic parameters. The endarterectomy specimens obtained in surgery are weighed and arranged anatomically (Figure 1, *B*).

Postoperative Care and Anticoagulation

Following surgery, patients are transferred to the cardiovascular intensive care unit. Standard monitoring includes a Swan-Ganz catheter, central venous pressure catheter, and arterial line. Inotropes are titrated to a target cardiac index of 1.8 L/min/m^2 to minimize reperfusion injury. In the presence of RV dysfunction, inhaled pulmonary vasodilators can be used. We aim to extubate on postoperative day 1, after weaning from inhaled pulmonary vasodilators. Close attention is paid to specific complications such as reperfusion injury, steal phenomenon, rethrombosis, and persistent pulmonary hypertension. Patients are typically restarted on full anticoagulation on postoperative day three. An echocardiogram and V/Q scan are obtained prior to discharge.

Data Collection and Statistical Analysis

Demographic and baseline characteristics were obtained at the time of diagnosis, including age, sex, race, body mass index (BMI), comorbidities, prior documented pulmonary embolism and/or deep vein thrombosis, 6-minute walk test, pulmonary function testing, echocardiography, and right heart catheterization data.

Operative variables collected included CPB and total circulatory arrest times. Any concomitant cardiac operations performed were recorded, as were complications of surgery, including in-hospital mortality, major disabling stroke, need for extracorporeal membrane oxygenation, renal failure, and prolonged ventilation. Postoperative hemodynamics were

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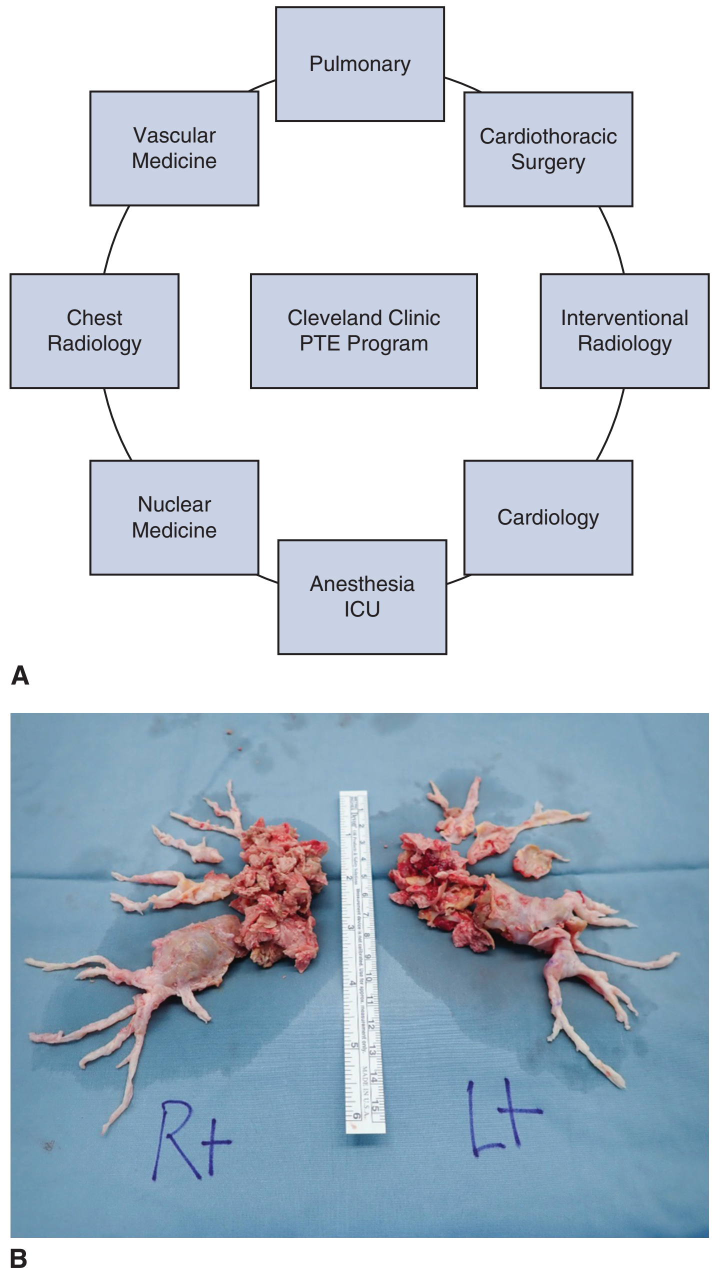


FIGURE 1. A, Cleveland Clinic's multidisciplinary chronic thromboembolic pulmonary hypertension (CTEPH) team model. B, Operative specimen. *PTE*, Pulmonary thromboendarterectomy; *ICU*, intensive care unit.

obtained as the final set recorded prior to removal of the pulmonary artery catheter in the intensive care unit. These values were used to determine changes in hemodynamic parameters following PTE.

Continuous variables are presented as mean ± standard deviation or median with interquartile range, with comparisons via the Wilcoxon rank-sum test or *t* test if normally distributed. Dichotomous variables were compared with the χ^2 test. A Kaplan-Meier curve was constructed to analyze postoperative survival following PTE. A *P* value $< .05$ indicated statistical significance. Protocols relating to data collection and analysis were approved by our Institutional Review Board (IRB 8097; approved April 15, 2022). The need for informed consent was waived given the retrospective nature of this study.

RESULTS

Preoperative

A total of 306 patients underwent PTE at our center between January 1997 and January 2022. Sixty-two patients (20.3%) were operated on before establishment of the CTEPH team in January 2011 (early era), and 244 patients (79.7%) were operated on afterward. There was a significant increase in the program volume of PTE following establishment of the CTEPH team in 2011 (Figure 2).

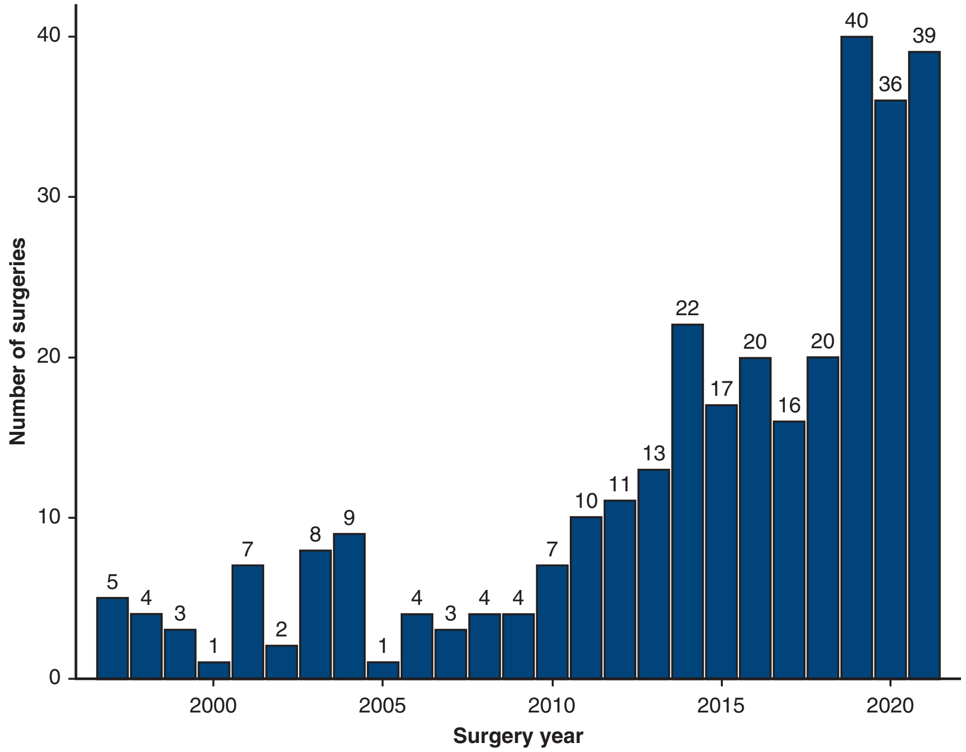


FIGURE 2. Temporal trend in number of pulmonary thromboendarterectomy (PTE) operations performed annually.

Patients' baseline characteristics are summarized in Table 1. The mean age for the entire cohort was 53 ± 14 years. BMI was significantly higher in the recent era compared to the early era (mean, 33.4 ± 7.9 vs 30.0 ± 7.4; $P = .004$). Medical comorbidities were roughly similar in the 2 groups. One noticeable difference, however, was that at time of presentation, patients in the early era more commonly presented with New York Heart Association functional class III/IV symptoms, whereas patients in the recent era presented with New York Heart Association class II/III symptoms.

Preoperative hemodynamic markers (summarized in Table 2) also were similar in the 2 groups, with several important exceptions. Early era patients had a lower left ventricular ejection fraction (mean, 54.7 ± 7.31% vs 60.5 ± 8.09%; $P < .001$) and more severe RV dysfunction (49.1% vs 25.0%; $P < .001$) despite a similar prevalence of tricuspid regurgitation. mPAP was similar in the 2 groups, with a mean value of 44.9 ± 11.2 mm Hg for the entire cohort (47.7 ± 11.5 mm Hg vs 44.5 ± 11.1 mm Hg; $P = .079$). Cardiac index also was similar in the 2 groups, with a mean value of 2.26 ± 0.63 for the entire cohort, consistent with marginal cardiac output (2.07 ± 0.52 vs 2.28 ± 0.64; $P = .19$). Finally, preoperative PVR was elevated, with a mean value of 7.40 ± 3.86 Wood units, and no statistical difference between the 2 groups (8.31 ± 4.51 vs 7.32 ± 3.81; $P = .35$).

Operative Data

CPB times and circulatory arrest times were longer in the early era compared to the recent era (mean, 176 ± 40 minutes vs 163 ± 31 minutes [$P = .015$] and 42 ± 16 minutes vs 36 ± 13 minutes [$P = .007$]). The most common concomitant procedures were tricuspid valve repair (TVr) (43 patients; 14%), patent foramen ovale closure (25 patients; 8.2%), and coronary artery bypass surgery (21 patients; 6.9%). More patients in the recent era underwent concomitant TVr (3.2% vs 17%; $P = .006$), while more patients in the early era underwent concomitant coronary artery bypass and patent foramen ovale closure (15% vs 4.9% [$P = .008$] and 15% vs 6.6% [$P = .042$], respectively).

There was no statistically significant difference in postoperative mPAP or change in preoperative mPAP to postoperative mPAP between the eras; however, both groups experienced a significant drop in mPAP from pre-PTE to post-PTE (mean, 18.2 ± 12.2 mm Hg) (Figure 3). Similarly, there were no significant differences in postoperative PVR and change in PVR between the 2 groups. PVR decreased by a mean of 4.6 ± 3.4 Wood units across the cohort after PTE. In absolute values, the mPAP and PVR were further reduced in the recent era compared to the early era (18.5 mm Hg and 4.6 Wood units, respectively, vs 13.6 mm Hg and 3.5 Wood units), likely not reaching statistical significance owing to the small sample size in the early era.

TABLE 1. Cohort baseline characteristics stratified by early era and recent era

Characteristic	Total cohort (N = 306)		Early era (N = 62)		Recent era (N = 244)		P value
	N	Value	N	Value	N	Value	
Demographics							
Patient age, y, mean ± SD	306	53 ± 14	62	50.5 ± 12.9	244	53.7 ± 14.2	.11
Female sex, n (%)	302	140 (46)	62	30 (48)	244	110 (45)	.64
BMI, kg/m^2, mean ± SD	302	32.8 ± 7.9	58	30.0 ± 7.4	244	33.4 ± 7.9	.0035
Race, n (%)							
Black	295	74 (25)	60	13 (22)	235	61 (26)	.49
White	295	213 (72)	60	47 (78)	235	166 (71)	.24
Other	295	8 (2.7)	60	0 (0)	235	8 (3.4)	.15
Comorbidities, n (%)							
Atrial fibrillation/flutter	295	31 (11)	55	2 (3.6)	240	29 (12)	.065
Congestive heart failure	306	77 (25)	62	17 (27)	244	60 (25)	.65
Peripheral arterial disease	306	37 (12)	62	7 (11)	244	30 (12)	.83
Hypertension	306	206 (67)	62	48 (77)	244	158 (65)	.058
Diabetes	306	63 (21)	62	11 (18)	244	52 (21)	.53
Smoking	303	163 (54)	62	35 (56)	241	128 (53)	.64
Renal dialysis	294	3 (1)	50	0 (0)	244	3 (1.2)	.43
Dyslipidemia	246	108 (44)	62	25 (40)	184	83 (45)	.51
COPD	306	54 (18)	62	11 (18)	244	43 (18)	.98
Interstitial lung disease	306	3 (0.98)	62	1 (1.6)	244	2 (0.82)	.57
Obstructive sleep apnea	306	85 (28)	62	11 (18)	244	74 (30)	.048
Disease characteristics, n (%)							
Previous IVC filter	306	169 (55)	62	55 (89)	244	114 (47)	<.0001
Confirmed previous pulmonary embolus	306	265 (87)	62	47 (76)	244	218 (89)	.0052
Hospitalization for pulmonary hypertension	306	156 (56)	37	14 (38)	244	142 (58)	.02

BMI, Body mass index; *COPD*, chronic obstructive pulmonary disease; *IVC*, inferior vena cava.

Early Outcomes

Perioperative events following surgery are shown in Table 3. There was a significant difference in hospital mortality between the 2 groups: 11% in early era versus 2.9% in recent era ($P = .0046$). Patients in the early era also had longer hospital stays (mean, 20.9 ± 15.1 days vs 15.6 ± 13.5 days; $P < .0001$) and a higher frequency of sepsis (11% vs 2.1%; $P = .008$), prolonged ventilation (59% vs 32%; $P = .008$) and renal failure (21% vs 1.6%; $P < .001$). There also was a trend toward significance in the need for postoperative extracorporeal membrane oxygenation: 13% in the early era versus 5.5% in the recent era ($P = .056$). The overall stroke rate was 1.8% with no significant difference between the two groups. There was no difference in need for reoperation, incidence of postoperative atrial fibrillation, or incidence of deep sternal wound infections.

Late Outcomes

There was a significant difference in long-term survival following PTE favoring the recent era (Figure 4). The mean overall follow-up was 4.5 ± 4.8 years, with a total of 1371.9 person-years available for analysis. The unadjusted 1- and 5-year survival after surgery was 80% and 78% in the early era, compared to 95% and 89% in the recent era. The overall 1- and 5- year survival in the total cohort was 92% and 88%, respectively.

DISCUSSION

In this work, we studied the role of implementing a multidisciplinary team approach to patients diagnosed with CTEPH. The establishment of a multidisciplinary team at our center in early 2011 may have been associated with early outcomes, through early surgical referral of appropriate patients, growth of our program, and standardization of perioperative care for patients undergoing PTE surgery. More importantly, the multidisciplinary CTEPH team approach is vital to selecting the optimal therapy for each patient. Identifying appropriate surgical candidates and the optimal timing for PTE is crucial for good outcomes. Careful assessment of hemodynamics, RV function, extent of thromboembolic disease, imaging/clinical discordance, window for intervention, and underlying coagulation disorders can be best served through the multidisciplinary team approach.

CTEPH remains underdiagnosed, and consequently, fewer patients are referred for surgical PTE, which provides the best chance for cure for appropriately selected patients. Several guidelines agree that PTE is the gold standard in all patients with operable disease and acceptable surgical risk.[9,15,16] The main goal of PTE is complete bilateral

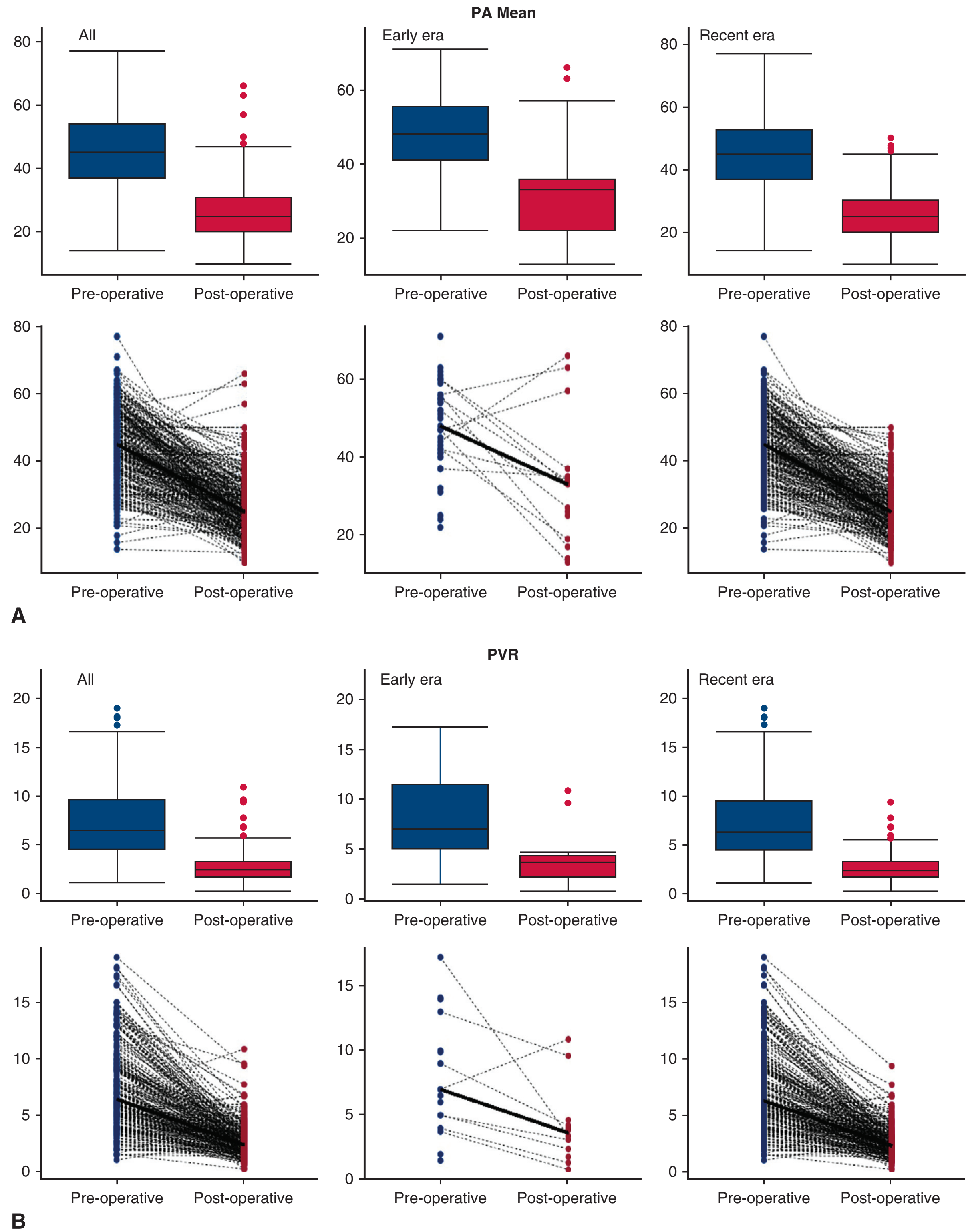


FIGURE 3. A, Change in mean pulmonary artery pressure (mPAP) preoperatively and postoperatively. The top panel shows this in boxplots. The box represents the 25th and 75th percentiles, the thick line represents the median, and the whiskers represent maximum and minimum of nonoutliers). The bottom panel displays line graphs which demonstrate the change (*dashed lines*) in PA mean preoperative (*blue dots*) to postoperative (*red dots*), and median change (*thick black line*). B, Change in mean pulmonary vascular resistance preoperatively and postoperatively. The top panel shows this in boxplots. The box represents the 25th and 75th percentiles, the thick line represents the median, and the whiskers represent the maximum and minimum of nonoutliers. The bottom panel displays line graphs showing the change (*dashed lines*) in mPAP from preoperatively (*blue dots*) to postoperatively (*red dots*) and the median change (*thick black line*).

TABLE 2. Perioperative characteristics and hemodynamics

	Total cohort (N = 306)		Early era (N = 62)		Recent era (N = 244)		
Variable	N	Value	N	Value	N	Value	*P* value
Echocardiography							
Preoperative ejection fraction, %, mean ± SD	302	59.4 ± 8.3	58	54.7 ± 7.3	244	60.5 ± 8.1	<.0001
Preoperative severity of RV dilation	305		61		244		.0009
None		43 (14)		4 (6.6)		39 (16)	
Mild		44 (14)		7 (11)		37 (15)	
Moderate		82 (27)		8 (13)		74 (30)	
Moderate-severe		34 (11)		11 (18)		23 (9.4)	
Severe		91 (30)		30 (49)		61 (25)	
Tricuspid valve regurgitation	300	228 (76)	62	47 (76)	238	181 (76)	.97
Six-minute walk test, mean ± SD							
Distance walked, m	222	308 ± 126	14	317 ± 148	208	308 ± 124	.77
Predicted walk %	212	56.9 ± 21.3	10	56.9 ± 20.6	202	56.9 ± 21.4	.93
Pulmonary function tests, mean ± SD							
FEV1/FVC	291	0.7 ± 0.1	50	0.7 ± 0.1	241	0.7 ± 0.1	.82
FEV1% predicted	289	76.1 ± 17.2	50	68.4 ± 13.8	239	77.7 ± 17.4	.0007
FVC % predicted	289	82.0 ± 18.5	50	75.4 ± 14.0	239	83.4 ± 19.0	.0019
Invasive hemodynamic measurements, mean ± SD							
Preoperative CVP, mm Hg	257	12.1 ± 6.6	20	10.3 ± 6.4	237	12.2 ± 6.6	.17
Postoperative CVP, mm Hg	256	10.2 ± 5.5	13	13.3 ± 5.4	243	10.0 ± 5.5	.044
⊿ CVP, mm Hg	248	2.1 ± 7.5	11	−0.9 ± 6.1	237	2.2 ± 7.6	.21
Preoperative cardiac index, L/min/m^2	247	2.3 ± 0.6	22	2.1 ± 0.5	225	2.3 ± 0.6	.19
Postoperative cardiac index, L/min/m^2	259	2.9 ± 0.7	16	2.8 ± 0.8	243	2.9 ± 0.7	.43
⊿ Cardiac index, L/min/m^2	235	0.7 ± 0.9	11	0.6 ± 0.8	224	0.7 ± 1.0	.89
Preoperative mPAP, mm Hg	282	44.9 ± 11.2	39	47.7 ± 11.5	243	44.5 ± 11.1	.079
Postoperative mPAP, mm Hg	259	26.4 ± 8.7	15	33.3 ± 16.8	244	26.0 ± 7.8	.13
⊿ mPAP, mm Hg	255	18.2 ± 12.2	12	13.6 ± 19.1	243	18.5 ± 11.8	.64
Preoperative PVR, Wood units	250	7.4 ± 3.9	19	8.3 ± 4.5	231	7.3 ± 3.8	.35
Postoperative PVR, Wood units	254	2.8 ± 1.5	12	4.2 ± 3.08	242	2.7 ± 1.4	.063
⊿ PVR, mm Hg	237	4.6 ± 3.7	8	3.5 ± 4.9	229	4.6 ± 3.7	.4

RV, Right ventricular; *FEV1*, forced expiratory volume in 1 s; *FVC*, forced vital capacity; *CVP*, central venous pressure; *mPAP*, mean pulmonary artery pressure; *PVR*, pulmonary vascular resistance.

thromboendarterectomy of disease in the pulmonary arterial system, with adequate reductions in PVR and RV afterload. Postoperative PVR has been shown to be the strongest predictor of long-term survival following PTE.[10,17] To this end, excellent outcomes following surgery rely on appropriate patient selection and identification of technically accessible disease burden. A multidisciplinary review of preoperative imaging helps identify with confidence patients who will benefit from this invasive therapy. Subtle imaging findings, such vascular webs or bands, bronchial artery collaterals, and irregular perfusion patterns, are best characterized by dedicated chest radiologists and pulmonary hypertension specialists. Conversely, a detailed imaging review will rule out patients with CTEPH mimickers, such as group 1 PAH with in situ thrombosis, sarcoma, pulmonary sarcoid, and others, who would have done poorly with surgery.[18]

Our multidisciplinary team meetings also identify patients early in the disease course who may benefit from surgery before the onset of RV dysfunction. In our series, surgical patients after the establishment of the CTEPH team in 2011 were less likely to have severe RV dysfunction compared to patients prior to 2011 but did have higher BMI and a greater incidence of obstructive sleep apnea. Early referral for curative surgery prior to the development of severe RV failure and multiorgan dysfunction may explain in part the improved outcomes after 2011. Advanced RV dysfunction can lead to poor cardiac output, tricuspid valve incompetence, hepatic congestion, and renal dysfunction, all of which elevate the operative risk.

With development of the CTEPH team, every patient with suspected CTEPH is reviewed, allowing for early surgical referral and optimal patient condition at time of surgery. This also highlights the importance of regional CTEPH expert centers where providers can refer patients for surgical evaluation earlier in their disease course.

The team has enacted several perioperative protocols to standardize the care of our surgical CTEPH patients based on currently available evidence and best practices. Protocols exist for anesthetic management in the operating room, anticoagulation regimens, as well as postoperative

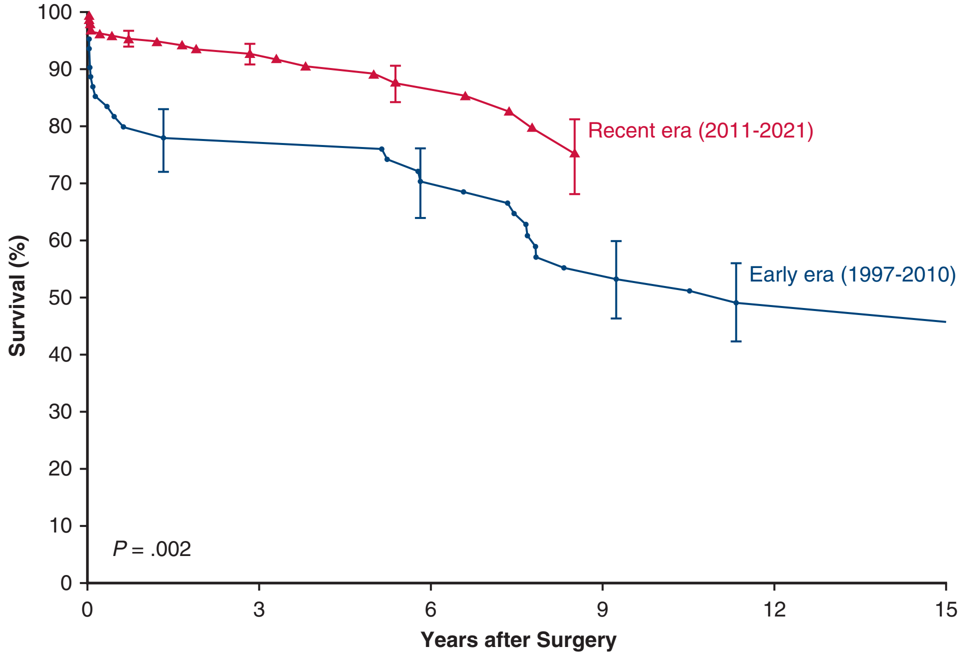
TABLE 3. Early outcomes after pulmonary thromboendarterectomy

Outcome	Total cohort (N = 306)		Early era (N = 62)		Recent era (N = 244)		*P* value
	N	Value	N	Value	N	Value	
ECMO support, n (%)	243	18 (7.4)	62	8 (13)	181	10 (5.5)	.056
Deep sternal wound infection, n (%)	303	0 (0)	62	0 (0)	241	0 (0)	
Sepsis, n (%)	305	12 (3.9)	62	7 (11)	243	5 (2.1)	.0008
Stroke, n (%)	305	4 (1.3)	62	1 (1.6)	243	3 (1.2)	.82
Reoperation for bleeding, n (%)	306	10 (3.3)	62	2 (3.2)	244	8 (3.3)	.98
Atrial fibrillation, n (%)	264	55 (21)	53	13 (25)	211	42 (20)	.46
Renal failure, n (%)	306	17 (5.6)	62	13 (21)	244	4 (1.6)	<.0001
Prolonged ventilation, n (%)	285	101 (35)	41	24 (59)	244	77 (32)	.0008
Hospital length of stay, d, mean ± SD	306	16.7 ± 13.7	62	20.9 ± 15.1	244	15.6 ± 13.1	<.0001
In-hospital death, n (%)	306	14 (4.6)	62	7 (11)	244	7 (2.9)	.0046

ECMO, Extracorporeal membrane oxygenation.

inotrope, fluid, and ventilator management. There is increased recognition of the unique complications of PTE, including reperfusion edema, steal phenomenon, and rethrombosis, to allow for early intervention and rescue prior to catastrophic events. The multidisciplinary team discussion for postoperative complications is of critical importance as well. This includes initiation of medical therapy for optimal hemodynamics and endovascular intervention for cases of pulmonary hemorrhage.

This study has several limitations, owing primarily to its retrospective nature. Our data show that forming a multidisciplinary team to care our PTE patients is associated with improved short- and long-term outcomes but unfortunately lack the granularity to suggest causation. Several confounding factors also may explain the improved outcomes. For one, surgical experience with PTE evolved throughout the period of this study, coinciding with increased program volume. Practice patterns, including case selection, also changed. In addition,



Number of patients at risk of death

Time (years)	Total	1	3	6	9	12	15
Early era	62	43	41	37	28	23	15
Recent era	244	188	106	49	16	–	–

FIGURE 4. Survival after surgery before and after institution of the chronic thromboembolic pulmonary hypertension (CTEPH) team. Each symbol represents a death positioned on the vertical axis by the Kaplan-Meier estimator. Vertical bars are confidence limits equivalent to ±1 standard error (68% confidence interval). The table at the bottom of the figure shows patients still at risk of death.

patients in the early era presented for PTE late in their disease course with worse RV dysfunction, which could have impacted their long-term survival. Follow-up data on RV remodeling were not available for this study to assess the impact on survival. Although it is plausible that multidisciplinary team meetings had a positive impact on selecting appropriate patients for surgery, such a claim cannot be supported by the present data. All the above leaves us with an association between the implementation of our multidisciplinary team with improved early outcomes, but not with causation.

One interesting trend was that of more frequent TVr during PTE in the recent era group. We posit that a lower threshold for TVr grew out of the growing experience with PTE and caring for these patients postoperatively. Comparing cohorts from different time periods inherently makes the analysis vulnerable to confounding variables that we might not have accounted for. Finally, our report excludes the results of CTEPH patients deemed inoperable treated with alternative strategies, such as pulmonary vasodilators or percutaneous interventions.

CONCLUSIONS

Managing CTEPH patients within a multidisciplinary team can aid the optimal selection of appropriate PTE candidates and can be associated with improved early outcomes. It also can help with program growth and early referral of patients in the ideal window for intervention. As CTEPH becomes a more widely recognized disease process, organizations hoping to start a successful treatment program may consider establishing a multidisciplinary CTEPH team of multiple experts involved in the care of these complex patients.

AUTHORSHIP STATEMENT

Drs Yang and Zaki had full access to all the data in the study and take responsibility for the integrity of the data and accuracy of the data analysis. Drs Yang and Zaki contributed to the study design, data analysis, and drafting of the manuscript. Drs Oh and Umana Pizano contributed to data acquisition, analysis, and interpretation. Drs Haddadin, Goyanes, Smedira, Elgharably, Zhen-Yu Tong, and Heresi contributed to the design and implementation of the research, analysis of results, and critical revisions of the manuscript.

Conflict of Interest Statement

Dr Heresi is an advisor and has teaching/speaking arrangements with Bayer Healthcare and is an advisor for Janssen Research and Development. Dr Elgharably receives speaking honoraria from LifeNet Health, Edwards LifeSciences, and LifeNet Health. All other authors reported conflicts of interest.

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