Pulmonary Angiography as a Quantifiable Measure of Successful Pulmonary Thromboendarterectomy in the Era of Expanding Indications

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Background

- **Pulmonary thromboendarterectomy (PTE)** is the guideline-recommended treatment for chronic thromboembolic pulmonary hypertension (CTEPH).[1]
- As disease recognition and surgical safety have improved, **patients with a lower burden of disease are being offered PTE**,[2] making it difficult to quantify treatment success using traditional parameters such as pulmonary vascular resistance (PVR).
- Here, we describe our experience using **pulmonary angiography (PAg) as a quality indicator** for PTE across disease severity.

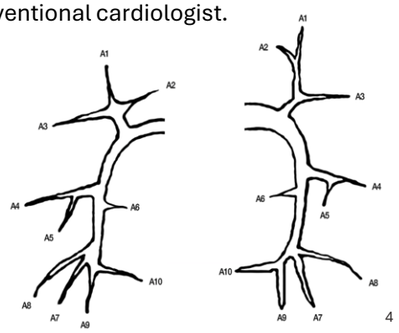
Methods

Patients:

- Single institution, retrospective
- 150 consecutive PTE 2016 – 2024 by two surgeons
- Excluded patients without pre-PTE PVR (n=4)

Pulmonary Angiogram Protocol

- Standard practice at Northwestern:
  - Pre-PTE: within 9 months
  - Post-PTE: mostly within 3-6 months[3]
- Most angiograms performed and read by single operator (DRS). All reads performed segmentally by interventional cardiologist.



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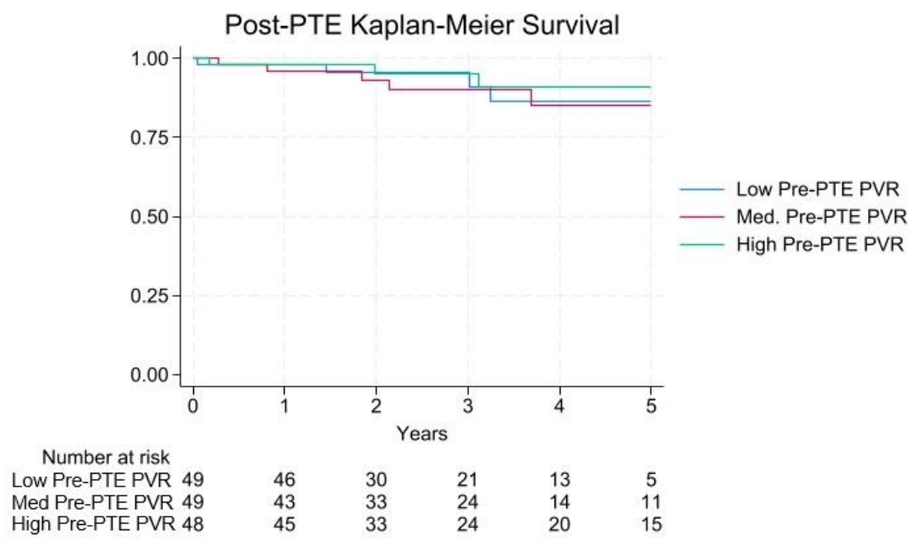
- Description converted to three-level score:
  - 0 = patent, no disease
  - 1 = partial occlusion (stenoses, webs, tapering)
  - 2 = total occlusion
- If a parent vessel (main PA, interlobar, basal trunk) was diseased, all downstream vessels were coded as diseased
- Percent improvement calculated as:

$$\frac{\#\ pairwise\ (pre\ vs.\ post)\ segments\ improved\ at\ least\ one\ point}{\#\ segments\ partially\ or\ totally\ occluded\ pre{-}PTE}$$

Results

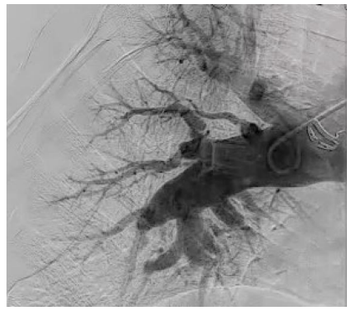
Parameter, median (IQR)	All N=146	Pre-PTE PVR Tertiles: Low N=49	Medium N=49	High N=48	p*
Age, mean (SD)	54 (15)	53 (17)	55 (14)	55 (15)	0.76
Female Sex, n (%)	87 (60%)	30 (61%)	27 (55%)	30 (63%)	0.73
DHCA time (min), mean (SD)	44 (13)	41 (14)	46 (13)	44 (12)	0.09
Distal disease (Madani 3 or 4 bilateral), n (%)	27 (18%)	10 (20%)	9 (18%)	8 (17%)	0.89
Mean PA pressure pre-PTE (mmHg), mean (SD)	43.7 (12.0)	34.3 (11.0)	43.8 (6.9)	53.2 (9.1)	**<0.001**
Pulmonary Vascular Resistance (dyn×s/cm^5)					
pre-PTE	504 (341-782)**	291 (208-341)	506 (456-563)	885(789-1084)	**<0.001**
3-6 months post-PTE	236 (176-363)**	195 (158-279)	273 (182-400)	269 (208-440)	**0.006**
% change	48 (19-67)	21 (5-44)	49 (29-64)	67 (62-77)	**<0.001**
>50% decrease, n (%)	61 (42%)	7 (14%)	20 (41%)	34 (71%)	**<0.001**
Residual disease > 400 dyn×s/cm^5 after PTE, n (%)	17 (12%)	3 (6%)	7 (14%)	7 (15%)	0.36
Number of diseased segments on PAg†					
pre-PTE	17 (13-18)**	15 (11-17)	17 (14-19)	18 (16-20)	**<0.001**
post-PTE	9 (5-14)**	7 (5-11)	9 (5-14)	9 (5-17)	0.42
% improvement	61.5 (36.9-82.8)	68.8 (37.5-82.4)	56.7 (40.0-83.3)	65.0 (25.0-80.0)	0.65
Mortality					
30-day, n (%)	1 (0.68%)	1 (2%)	0 (0%)	0 (0%)	1.00
1-year, n (%)	4 (2.7%)	1 (2%)	2 (4%)	1 (2%)	1.00
3-year, n (% [95% CI from KM])	8 (6% [3-13%])	2 (5% [1-17%])	4 (10% [4-25%])	2 (5% [1-17%])	
5-year, n (% [95% CI from KM])	12 (13% [7-22%])	4 (15% [6-38%])	5 (15% [6-33%])	3 (9% [3-26%])	
Post-PTE echo					
Freedom from Mod-Sev. RV dilation, n (%)	85 (82%)	33 (94%)	28 (85%)	24 (67%)	**0.01**
Freedom from Mod-Sev. RV dysfunction, n (%)	97 (80%)	40 (91%)	30 (83%)	27 (64%)	**0.01**
Home O2 use					
pre-PTE, n (%)	54 (37%)**	17 (35%)	20 (41%)	17 (35%)	0.79
last follow up, n (%)	8(7%)**	2 (5%)	4 (11%)	2 (5%)	0.59
Taking pulmonary vasodilator					
pre-PTE, n (%)	90 (62%)**	26 (53%)	30 (61%)	34 (71%)	0.20
last follow up, n (%)	32 (24%)**	5 (11%)	11 (25%)	16 (35%)	**0.03**
BPA after PTE, n (%)	41 (28%)	17 (35%)	13 (11%)	11 (23%)	0.42

†Patients with usable PAg: 135 pre-PTE, 122 post-PTE, 116 both
*Comparison across first, second, and third cohorts with one-way ANOVA, Kruskall-Wallis, chi-squared, or Fisher's exact test as appropriate.
** Pairwise comparisons were performed by Wilcoxon matched-pairs signed-rank test or McNemar's test as appropriate. Denotes statistical significance at p<0.001 based on pairwise tests.



Key Findings

- The **number of diseased segments** identified on pre-PTE PAg **increased** with the **pre-PTE PVR tertile**.
- There were **no differences in mortality** at 30-days or 1-year across groups.
- The **low starting PVR** cohort had **greater freedom from mod-severe RV dilation and dysfunction** than the high starting PVR group 3-6 months after PTE (p=0.01).
- Those with a **higher pre-PTE PVR** were **more likely** to be **on pulmonary vasodilators** at last follow up (p=0.03).
- While **percentage decrease in PVR** and number of **patients achieving >50% reduction** in PVR significantly **differed** across the groups (p<0.01), the **number of diseased segments** on post-PTE PAg (p=0.4) and **percentage improvement** in diseased segments (p=0.7) were **not affected by pre-PTE PVR**.



Conclusions

- **Traditional quantifiable metrics of PTE success**, such as percent and absolute reduction in PVR, **are affected** by the **starting hemodynamic severity** of disease.
- Alternatively, **post-PTE pulmonary angiography** can be evaluated separately as a **quality indicator** for success, **independent** of patients' **baseline hemodynamics.**

References

1. Humbert M, Kovacs G, Hoeper MM, et al. 2022 ESC/ERS Guidelines for the diagnosis and treatment of pulmonary hypertension. Eur Respir J. Jan 2023;61(1)
2. Jenkins DP, Tsui SS, Taghavi J, et al. Pulmonary thromboendarterectomy-the Royal Papworth experience. Ann Cardiothorac Surg. 2022;11(2):128-132.
3. Cannon JE, Su L, Kiely DG, et al. Dynamic Risk Stratification of Patient Long-Term Outcome After Pulmonary Endarterectomy: Results From the United Kingdom National Cohort. Circulation. 2016;133(18):1761-1771.
4. Diagram courtesy of Royal Papworth Hospital