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Original Article

Radiology Section

Pulmonary Artery Obstruction Index as a Predictor of Right Ventricular Dysfunction in Patients with Acute Pulmonary Thromboembolism: A Cross-Sectional Study

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ABSTRACT

Introduction: Acute Pulmonary Thromboembolism (PTE) is a severe and often fatal venous thromboembolism that leads to haemodynamic instability due to Right Ventricular Dysfunction (RVD) and circulatory failure. Early diagnosis can reduce mortality to under 10%. Computed Tomography Pulmonary Angiography (CTPA) is the preferred imaging method, with 95% sensitivity for distal clots. The present study involving 70 PTE patients evaluated the Pulmonary Artery Obstruction Index (PAOI) as a predictor of complications.

Aim: To identify the efficacy of the PAOI in predicting RVD in acute PTE patients.

Materials and Methods: This cross-sectional study was conducted in the Department of Radiodiagnosis, Barnard Institute of Radiology, Rajiv Gandhi General Government Hospital, Chennai, Tamil Nadu, India between September 2023 and August 2024. The study included patients with acute PTE who showed visible thrombi on CTPA. Patients with a known history of cardiac or pulmonary diseases, those who were unable to provide consent for the study, pregnant patients, lactating mothers and patients with renal failure were excluded. CTPA was performed using a GE Revolution 128-slice Computed Tomography (CT) scanner and a Two-dimensional Echocardiography (2D Echo) was conducted with a Mindray Ultrasonography (USG) machine to compare PAOI with RVD. The Receiver Operating Characteristic (ROC) curve was used to determine the cut-off value of PAOI. The association between categorical variables and the outcomes was evaluated using Chi-square and Fisher's-exact tests.

Results: The most common PAOI score range was 41-50%, observed in 25 patients (35.80%). The right lower lobe branch was the most frequently involved pulmonary artery, affected in 61 patients (87.14%), followed by the right middle lobe artery in 52 patients (74.28%). Female patients had a higher incidence of RVD than their male counterparts. All 35 patients (50% of the study population) with RVD had a PAOI >42% (p-value <0.001), whereas 97.14% of those without RVD had a PAOI ≤42%.

Conclusion: The study concluded that a PAOI >42% in thromboembolism had a sensitivity of 100% and a specificity of 97.1% for predicting RVD in patients with acute pulmonary embolism. A higher PAOI (clot burden) increases the likelihood of RVD, particularly when central arteries are involved.

Keywords: Angiography, Clot burden score, Computed tomography, Pulmonary hypertension

INTRODUCTION

Acute PTE is a significant cause of morbidity and mortality globally, resulting from blood clots that obstruct pulmonary arteries, typically originating from deep vein thrombosis. It manifests with symptoms such as sudden onset dyspnoea and chest pain, though these can be non specific, often leading to diagnostic delays [1]. The condition can result in RVD and haemodynamic instability, particularly when central arteries are involved [2]. Computed Tomography Pulmonary Angiography (CTPA) is the preferred diagnostic method for detecting acute Pulmonary Embolism (PE) due to its accuracy and reliability [3].

However, despite advancements in diagnostic techniques, survival rates for acute PE remain inconsistent, with short-term survival ranging from 71% to 95% and long-term survival falling between 61% and 75% [4]. To improve these outcomes, rapid and reliable risk assessment has become a priority in managing acute PE. Prognostic indices derived from CTPA are highly useful because they are usually direct, simple and widely accessible.

One such index is the Pulmonary Artery Occlusion Index (PAOI). This scoring system evaluates clot burden in PE, giving greater weight to fully occluded vessels compared to partially obstructed ones, thereby providing insight into blood flow beyond the clot [5].

The PAOI calculates clot burden in PE by multiplying two factors: the number of segmental branches arising from the site of the proximal clot (N) and the degree of obstruction (D), where '1' represents partial obstruction and '2' represents total obstruction. An embolus in a segmental artery is assigned '1' point, multiplied by D for partial or complete occlusion, giving a maximum score of '2' for a completely occlusive clot. Emboli in proximal arteries are scored as though each downstream segmental branch has the same degree of obstruction. Subsegmental emboli are treated as partial obstructions of their respective segmental arteries. The maximum obstruction score for a patient is 40 points (20 per lung), which is then expressed as a percentage in the PAOI [5].

Further correlation of the PAOI with echocardiographic findings to predict complications such as RVD has been attempted in a few studies, which aimed to establish a cut-off value for this purpose, with the cut-off values in those studies ranging between 40% and 60% [5-8]. These studies were conducted in foreign populations with relatively small sample sizes or used lower-slice CT machines with limited spatial resolution. Therefore, there is a pressing need for studies to establish the efficiency of the PAOI in assessing clot burden in acute PTE, predicting cardiovascular complications and effectively categorising patients by severity to guide appropriate therapy.

Thus, the objectives of the present study were to assess the PAOI of patients diagnosed with acute PTE using CTPA on a 128-slice CT scanner with high spatial resolution to better visualise distal segmental arteries, compare the findings with Two-dimensional

Echocardiography (2D Echo) and evaluate the PAOI's efficiency in predicting right ventricular dilation and dysfunction.

MATERIALS AND METHODS

The present is a cross-sectional study conducted in the Department of Radiodiagnosis, Barnard Institute of Radiology, Rajiv Gandhi General Government Hospital, Chennai, Tamil Nadu, India, lasting for one year between September 2023 and August 2024. Institutional scientific and Ethical Committee approvals (No. 10092023) were obtained by September 2023, prior to the initiation of the study. Consent to participate in the study was obtained from each patient before their inclusion.

Inclusion criteria: Patients with acute PTE undergoing CT Pulmonary Angiography (CTPA).

Exclusion criteria:

- Previous allergic reaction to contrast media;
- Known history of cardiac or pulmonary diseases;
- Inability to provide informed consent;
- Pregnancy and lactation;
- Renal failure.

Sample size calculation: Based on a study conducted by Praveen Kumar BS et al., the specificity of the CT PE index in predicting RVD in PTE patients was 87.0% and the proportion of patients with RVD was 31.4% [5]. The sample size was calculated using the following formula:

$$N=\frac{Z\alpha^{2*}\{SP\ (1\text{-}SP)\}}{d^2\ (1\text{-}P)}$$

SP= Specificity = 87%

d= error margin or precision= 10%

p= proportion of patients with RVD= 31.4%

N= (1.96*1.96*0.87*0.13)/(0.1*0.1*0.686))= 63 rounded off to 65

Minimum sample size required N=65

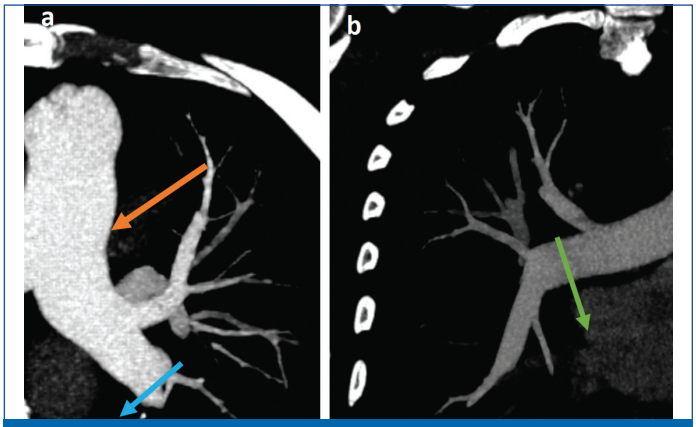
The study included a total of 70 patients diagnosed with acute PTE using CTPA and they were subjected to 2D Echo to assess for the occurrence of complications such as right ventricular failure.

Study Procedure

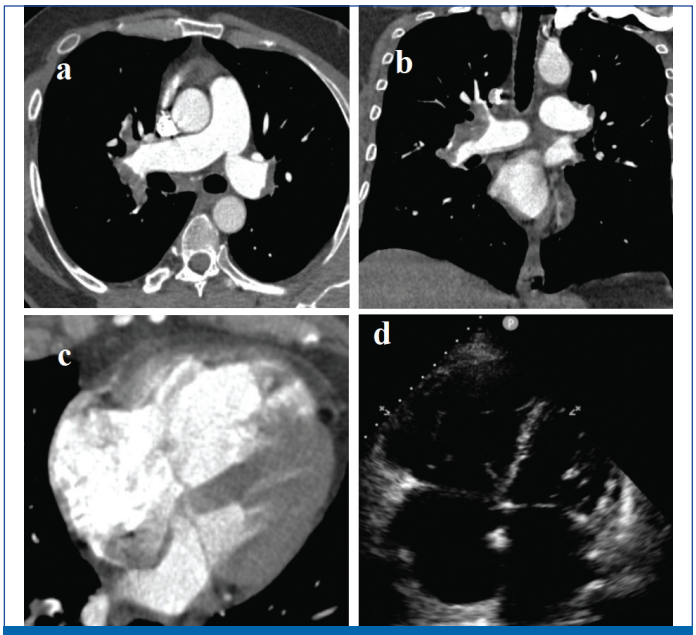
Methodology: The CTPA examinations were performed using a GE Revolution 128-Slice Helical CT scanner and followed the established CTPA protocol. The injections were administered automatically. An 18-20 G catheter was placed in the vein of all patients for the injection. A volume of 120-150 mL of 350 mg/mL iohexol (Omnipaque) was administered at a rate of 4 mL/s using an automatic injector as part of the CTPA protocol. The images were obtained when the contrast agent in the right pulmonary artery reached a density of 120 Hounsfield Units (HU). All CTPA examinations were conducted with the patient in the supine position, from head to toe. The images were acquired from the lung apex to the diaphragm level using the following parameters: 120 kVp, 160 mAs, a slice thickness of 1.25 mm, a pitch factor of 1.675:1 and a rotation time of 0.98 seconds.

In all patients, the diagnosis of acute PTE was established through the visualisation of one or more emboli as hyperattenuating filling defects in the enhancing lumen of the pulmonary artery [9]. The Qanadli index was used to calculate clot burden. The Qanadli scoring system considers both the location and degree of pulmonary artery obstruction [10]. The normal appearance of the main pulmonary and segmental pulmonary arteries is shown in [Table/Fig-1].

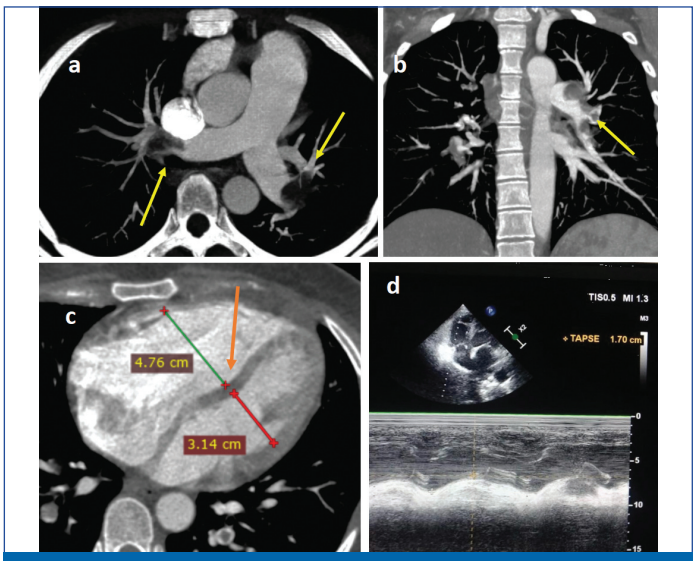
To calculate the PAOI, the Qanadli score was first calculated. The arterial vasculature of each lung was considered to have 10 segmental arteries (three to the upper lobes, two to the middle lobe and the lingula and five to the lower lobes). Complete occlusion of a segmental artery was assigned a score of 2, while partial occlusion was given a score of 1. The proximal lobar arteries received a score equal to the number of segmental arteries [Table/Fig-2,3] arising distal to them, depending on the degree of occlusion, as previously



[Table/Fig-1]: CT Pulmonary Angiogram (CTPA): a) Axial image showing normal contrast opacification of main pulmonary artery (orange arrow) and left pulmonary artery (blue arrow); b) Coronal image showing right pulmonary artery.



[Table/Fig-2]: a) Axial; b) Coronal MIP CTPA images showing partial filling defects involving bilateral main pulmonary arteries (PAOI-50%); c) CTPA MPR; d) 2D Echo 4 chamber view showing dilated right ventricle. TAPSE- 15 mm.



[Table/Fig-3]: a) Axial; b) Coronal Maximum intensity projection (MIP) CTPA images showing partial occlusion of bilateral pulmonary arteries marked by yellow arrows (PAOI-50%); c) Multiplanar Reconstruction (MPR) CTPA 4-chamber image showing dilated right ventricle with bowing of interventricular septum towards the lumen of the left ventricle (marked by the orange arrow); d) 2D Echo M mode image showing borderline TAPSE values. The patient later developed RVD.

described for segmental arteries. For example, if the right upper lobar artery showed complete occlusion, it was assigned a score of 6; in the case of partial obstruction, it would be assigned a score of 3, with 1 point for each pulmonary segment supplied by the lobar artery. Therefore, the maximum total score could be 40, in the case of complete occlusion of the main pulmonary artery [10].

To calculate the obstruction index, the Qanadli score was converted into a percentage by multiplying the score by 100 and dividing by 40. Therefore, the CT obstruction index can be expressed as Σ (n d)/40 × 100, where n is the value of the proximal thrombus in the pulmonary arterial tree, equal to the number of segmental branches arising distally (minimum, 1; maximum, 20) and d is the degree of obstruction (minimum, 0; maximum, 2) [6,11].

A 2D transthoracic echocardiography (2D Echo) was performed using a Mindray ultrasound system. Chamber sizes and Right Ventricular (RV) dimensions were measured according to guidelines. RV Dysfunction (RVD) was diagnosed based on RV dilatation and reduced Tricuspid Annular Planar Systolic Excursion (TAPSE) [12].

STATISTICAL ANALYSIS

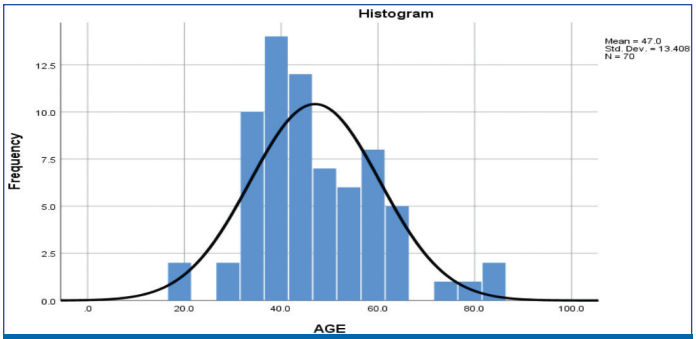
Statistical analysis was conducted using the Statistical Package for Social Sciences (SPSS) software, version 20.0, SPSS Inc., Chicago, USA. The associations between categorical variables and the outcomes were evaluated using the Chi-square and Fisher's-exact tests. The ROC curve was utilised to construct the cut-off value for the PE index.

RESULTS

The study population consisted of 40 males (57.1%) and 30 females (42.9%), with 22 participants (31.4%) in the age group of 31-40 years [Table/Fig-4,5]. The most common PAOI score range was 41-50%, observed in 25 patients (35.80%) [Table/Fig-6]. The most frequently involved pulmonary artery was the right lower lobe branch, which was affected in 61 patients (87.14%), followed by the right middle lobe artery in 52 patients (74.1%) [Table/Fig-7]. The central pulmonary arteries (main pulmonary artery, right pulmonary artery and left pulmonary artery) were involved in 32 patients (45.7%), with the right pulmonary artery being the most commonly affected.

Age group (in years)	Frequency	Percentage
21-30	4	5.70%
31-40	22	31.40%
41-50	20	28.57%
51-60	14	20%
>60	10	14.20%
Total	70	100%

[Table/Fig-4]: Age distribution of study participants.



[Table/Fig-5]: Histogram image depicting the age distribution of acute Pulmonary Thromboembolism (PTE) in the study, showing maximum number of patients in age group around 40.

PAOI	Upto 10%	11-20%	21-30%	31-40%	41-50%	>50%	Total
Frequency	8	12	10	4	25	11	70
Percentage	11.40%	17.10%	14.20%	5.80%	35.80%	15.70%	100%

[Table/Fig-6]: Distribution of Pulmonary Artery Obstruction Index (PAOI).

Pulmonary arteries	Number	Percentage (%)
Right lower lobe	61	87.10%
Right middle lobe	52	74.30%
Right upper lobe	47	67.10%
Left lower lobe	50	71.40%
Left upper lobe	34	48.60%
Right pulmonary artery	28	40.00%
Left pulmonary artery	14	20%
Main pulmonary artery	8	11.40%

[Table/Fig-7]: Involvement of pulmonary arteries in acute Pulmonary Thromboembolism (PTE).

Among the study participants, 35 patients (50%) developed right ventricular dilatation and dysfunction. Of these patients, RVD was more common in the female population, with 20 females (57.14%) affected compared to 15 males (42.85%).

Of the participants, 20 patients (28.57%) had dyspnoea as the only symptom and 8 of these (11.42%) developed RVD. A total of 11 patients (15.71%) had chest pain as the main symptom, while another 29 patients (41.42%) presented with both dyspnoea and chest pain. Of these patients, 4 (5.71%) and 17 (24.28%) developed RVD, respectively. The remaining 10 patients (14.28%) had neither chest pain nor dyspnoea and 6 of these (8.57%) developed RVD [Table/Fig-8]. Thus, it is evident that clinical symptoms and criteria alone are insufficient to predict complications in patients with acute PTE.

Symptoms	Number	Right ventricular dyfunction
Dyspnoea only	20 (28.57%)	8 (11.42%)
Chest pain only	11 (15.71%)	4 (5.71%)
Dyspnoea and chest pain	29 (41.42%)	17 (24.28%)
Neither chest pain nor dyspnoea	10 (14.28%)	6 (8.57%)

[Table/Fig-8]: Various symptoms in patients presenting with acute Pulmonary Thromboembolism (PTE).

Among the patients who developed RVD, the mean PAOI was 53.6%. All 35 patients (50% of the study population) with RVD had a PAOI ≥42% (Fisher's-exact test, p-value <0.001) [Table/Fig-9], whereas 97.14% of those without RVD had a PAOI <42%. A ROC curve was generated, with an Area Under the Curve (AUC) of 0.999 for a PAOI value of 42% [Table/Fig-10]. Thus, the study identified a PAOI of 42% as a cut-off value for predicting RVD in patients with acute PTE, with a sensitivity of 100% and a specificity of 97.1% (95% confidence interval).

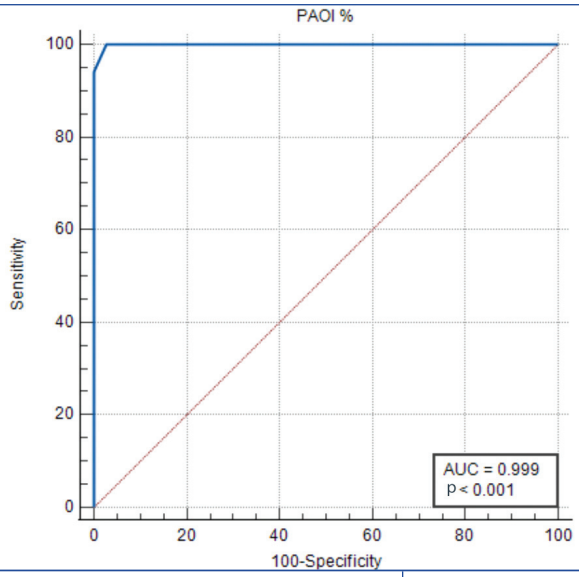
Variable		RVD				Fisher's-exact test p-value
		Present		Absent		
		n	%	n	%	
PAOI%	>42	35	97.2%	1	2.8%	<0.001
	</=42	0	0.0%	34	100.0%	
	Total	35	50.0%	35	50.0%	

[Table/Fig-9]: Association between PAOI and Right Ventricular Dysfunction (RVD).

DISCUSSION

The outcome of the study implies a significant association between an increased PAOI (>42%, p <0.001) and the incidence of RVD in patients with acute PTE. The 128-slice CT scanner was more efficient in detecting segmental artery thrombosis than lower-slice CT machines, enhancing both the accuracy and efficiency of detecting and quantifying clot burden in acute PTE.

The incidence of RVD in the current study population was observed in 35 patients, accounting for 50% of the total cohort. Similarly,



Area under the ROC curve (AUC)	0.999
Standard Error	0.000995
95% Confidence interval	0.947 to 1.000
z statistic	501.753
Significance level p (Area=0.5)	<0.001

[Table/Fig-10]: Receiver Operating Characteristic (ROC) analysis to predict RVD by PAOI%.

Kucher N et al., reported an RVD incidence of approximately 40% in patients with acute PTE diagnosed using CTPA [13]. Additionally, Piazza G and Goldhaber SZ, documented a higher incidence, ranging from 50% to 60% [14]. These findings indicate that the incidence of RVD observed in this study is consistent with previously reported data, particularly in studies focusing on moderate to severe PTE.

The higher incidence of thrombus in the right lower lobe pulmonary artery, observed in 61 patients (87.14%), may be attributed to factors such as the greater proportion of right ventricular output directed toward the right lower lobe due to gravity, the larger diameter of the artery and its alignment in an upright position. A similarly elevated incidence of thrombus in the right lower lobe pulmonary artery has been reported in studies by Winer-Muram HT et al., (70-90%) and Musset D et al., (80-85%) [15,16]. These studies further suggest that right lower lobe involvement may be associated with a higher PAOI, which in turn increases the risk of RVD.

The PAOI is a measure capable of predicting complications in acute PTE based on CTPA findings and is highly reproducible with low interobserver variability. The PAOI and the Qanadli score are largely dependent on the clot burden and the location of the clot. A large clot in a distal artery may have a low clot burden and, hence, a low PAOI and Qanadli score compared to one involving the main pulmonary artery. Similarly, the higher the clot burden, the higher the PAOI, Qanadli score and probability of complications [2]. The study has yielded a cut-off for the PAOI of 42%, with a sensitivity and specificity of 97% and 100%, respectively. A study conducted by Qanadli using a 16-slice CT machine reported a cut-off of 40% for the obstruction index, with a sensitivity of 90% [10].

The central pulmonary artery involvement in patients with acute PTE, as reported in studies conducted by Praveen Kumar BS et al., Attia NM et al., and Higazi MM et al., was found to be 60%, 45% and 46%, respectively [5,7,17]. The central pulmonary artery involvement in the present study is 45.71%. The incidence of symptoms, such as chest pain and dyspnoea, was also consistent with the findings of the present study.

Limitation(s)

While every effort was made to minimise potential biases and shortcomings, no limitations were evident in the execution or analysis of the study.

CONCLUSION(S)

The present study found a significant association between increased PAOI and the incidence of RVD in patients with acute PTE. A PAOI of 42% was identified as a cut-off value for predicting RVD in patients with acute PTE, demonstrating a sensitivity of 100% and a specificity of 97.1%. The CTPA is an efficient tool for predicting complications, such as RVD, in patients with PE. CTPA accurately predicted complications in these patients using the Qanadli scores and PAOI non invasively, aiding in careful monitoring and early management, thereby reducing morbidity. Moreover, it is clear that the clot burden and PAOI are directly related to RVD; that is, the higher the clot burden, the greater the possibility of RVD. The efficiency of the 128-slice CT, compared to the routinely used 16-slice CT, in assessing the nature, severity and extent of pulmonary artery thrombi in distal segmental arteries makes it a valuable tool for evaluating acute PTE.

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