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RADIOLOGICAL ASSESSMENT OF RIGHT HEART STRAIN AND PULMONARY EMBOLISM SEVERITY USING CTPA METRICS

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Abstract: Pulmonary thromboembolism (PTE) poses a significant risk of acute right-sided heart failure and mortality. Computed tomography pulmonary angiography (CTPA) serves as the gold standard for assessing acute pulmonary embolism (APE) risk. This study aims to determine the potential risk of acute right-sided heart failure in APE patients through semi-quantitative CTPA measurements, including the pulmonary arterial obstruction index (PAOI) and evaluation of right atrium (RA) dimensions, left atrium (LA) dimensions, RA/LA ratio, and inferior vena cava (IVC) contrast reflux.

Method: This retrospective study involved 50 patients, undergoing initial and follow-up CTPA's at the Institute of Radiology in Skopje, between January 2018 and January 2021, who were initially diagnosed with APE. They all exhibited varied degrees of pulmonary arterial obstruction index, constituting the study group, while their follow-up CT's after treatment and resolution of emboli, comprised the control group. PAOI was semi-quantitatively correlated with RA and LA dimensions, RA/LA ratio, and IVC contrast reflux using axial CT scans on the initial and follow up CTPA's.

Results: Among the 50 APE patients, 31 were male and 19 were female. Significant positive correlations were observed between PAOI and RA short axis, RA/LA short and long axis ratio, and IVC contrast reflux. Conversely, negative correlations were found between PAOI and LA dimensions.

Discussion: The correlations observed between PAOI measurements and cardiac dimensions in APE patients shed light on the condition's hemodynamic implications. A negative correlation with left atrium dimensions suggests reduced left ventricular preload with increasing pulmonary arterial obstruction. Conversely, positive correlations with right atrium dimensions and RA/LA ratio underscore the impact of elevated pulmonary vascular resistance on right heart strain, indicating a heightened risk of right-sided heart failure.

The association between PAOI and IVC contrast reflux highlights the significance of venous congestion in APE, further exacerbating right heart strain. These findings emphasize the importance of assessing right heart dimensions and venous congestion in APE prognosis. PAOI, along with these parameters, serve as valuable prognostic indicators, aiding in risk stratification and guiding therapeutic decisions to minimize adverse outcomes in APE patients.

Conclusion: PAOI measurements, IVC contrast reflux, RA short axis, and RA/LA short and long axis ratio serve as reliable CT prognostic markers for APE severity, risk of right-sided heart failure, and adverse outcomes. These markers aid in timely diagnosis and therapy selection for APE patients.

Keywords: Acute pulmonary embolism (APE), Pulmonary arterial obstruction index (PAOI), Right heart failure (RHF), Right atrium (RA), Inferior vena cava contrast reflux (IVC), Computed Tomography Pulmonary Angiography (CTPA).

1. INTRODUCTION

Pulmonary thromboembolism (PTE), a prevalent cardiovascular ailment, poses a significant public health and ranks as the third most common cause of in-hospital cardiovascular mortality, trailing only myocardial infarction and stroke. It stands as a leading cause of hospitalization in Europe. The annual incidence is estimated to range between 100 and 200 cases per 100,000 individuals (Al Dandan et al., 2020; Konstantinides SV et al., 2019; Sin D. et al., 2021). In the United States, it is annually afflicting over 900,000 individuals (1-2 per 1000). Alarmingly, 10-30% of patients succumb within the initial month of diagnosis, with sudden death as the first symptom for up to a quarter of cases. Furthermore, approximately one-third of patients with DVT/PTE experience recurrence within the first decade (Virani SS et al., 2020; CDC, 2022). This condition often presents with an insidious clinical profile, lacking typical symptoms and signs, thereby complicating diagnosis. PTE often manifests as dyspnea at rest (50%) or on exertion (27%), cough (22.9%), indications of deep vein thrombosis (DVT) (24%), chest pain (39%), and syncope (5%) (Moore AJE, 2018).

Given that right heart failure is the leading cause of mortality in PTE patients, a comprehensive evaluation of right heart function is essential, facilitated by computed tomographic pulmonary angiography (CTPA). While echocardiography remains the gold standard for diagnosing right heart failure, CTPA emerges as the preferred diagnostic modality for acute pulmonary embolism (APE). With its high specificity in detecting thrombi in distal sub-segmental arteries and the capability to quantify them with up to 95% accuracy, CTPA also enables

simultaneous identification of right heart failure signs and other lung pathologies (Ibrahim H., 2021; Zantonelli G., 2022; Beenen LFM, 2018). CTPA facilitates quantitative assessment of right heart strain by measuring dimensions of the right and left heart cavities and their ratio, pulmonary trunk and main pulmonary arteries diameter, and pulmonary artery obstructive index. Additionally, semi-quantitative, visual grading of contrast reflux in the inferior vena cava (IVC) serves as a dynamic marker for acute pulmonary arterial hypertension. Timely risk stratification of PTE patients is clinically imperative (Leidi A., 2022; Higazi MM, 2020).

CTPA serves as a valuable diagnostic tool for early PTE detection and assessing the risk of developing right heart failure and circulatory collapse. This study aims to assess the risk of acute right heart failure in acute pulmonary embolism patients using semi-quantitative CTPA measurements. We will evaluate the relationship between the pulmonary artery obstruction index (PAOI) and various cardiac dimensions, including the short and long axes of the left atrium (LA), right atrium (RA), RA/LA ratio, and inferior vena cava (IVC) reflux degree.

2. METHOD

The cohort involved 50 patients, undergoing initial and follow-up CTPA's at the Institute of Radiology in Skopje, between January 2018 and January 2021, who were initially diagnosed with APE. They all exhibited varied degrees of pulmonary arterial obstruction index, constituting the study group, while their follow-up CT's after treatment and resolution of emboli, comprised the control group. PAOI was semi-quantitatively correlated with RA and LA dimensions, RA/LA ratio, and IVC contrast reflux using axial CT scans on the initial and follow up CTPA's. CTPA was performed on a 128-slice Somatom Definition AS+ CT scanner following the standard APE diagnostic protocol, employing the bolus-tracking technique. Axial scans and multi-planar reconstructions analyzed thrombus location and pulmonary arterial obstruction degree using Qanadli et al.'s semi-quantitative index (Qanadli S. D. et al., 2001). Each lung's arterial trunk consists of 10 segmental branches, with thrombus presence in a segmental artery receiving 1 point. Complete or partial occlusion is scored 0-2, yielding a maximum CT obstruction index of 40. A percentage index is calculated $\{(n \times d)/40\} \times 100$, where n is affected segmental arteries (1-20) and d is occlusion degree (1-2), Figure 1. An index of 40-60% indicates intermediate to high-risk PTE without hypotension.

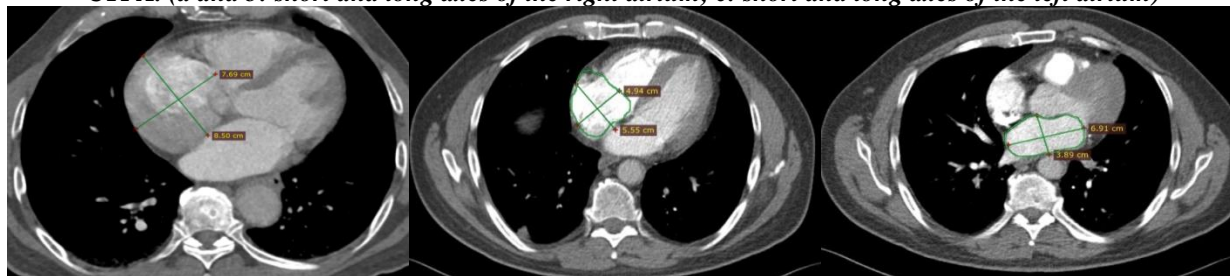
Figure 1: Detection and Quantification of Thrombi through the Pulmonary Arterial Obstruction Index



Source : Picture archiving and communication system (PACS) of Institute of Radiology, Skopje

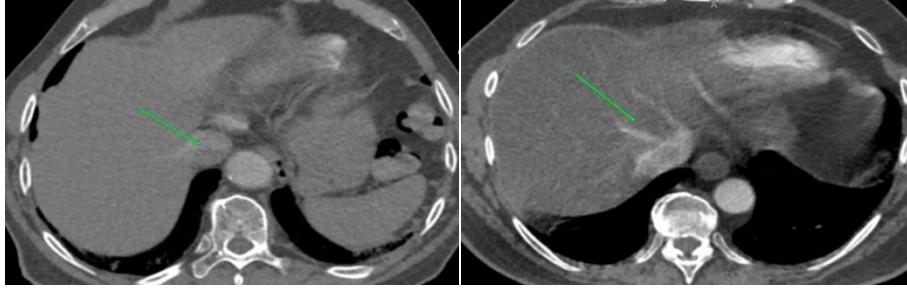
Measurements of right and left atrium axes, their ratio, and IVC contrast reflux semi-quantitative grading were correlated with PAOI to detect acute pulmonary hypertension and right heart failure risk. IVC reflux grading ranged from 0 (none) to 4 (reflux to distal hepatic veins), Figure 2 a-c, Figure 3 a-b.

Figure 2a-c: Measurement of the short and long axes of the right and left atrium from axial scans in CTPA. (a and b: short and long axes of the right atrium; c: short and long axes of the left atrium)



Source : Picture archiving and communication system (PACS) of Institute of Radiology, Skopje

Figure 3a-b: Semi-quantitative grading of contrast reflux in IVC. (a) Grade 1: Contrast reflux observed only at the level of the IVC; (b) Grade 3: Contrast reflux traced to the middle segment of the hepatic veins.



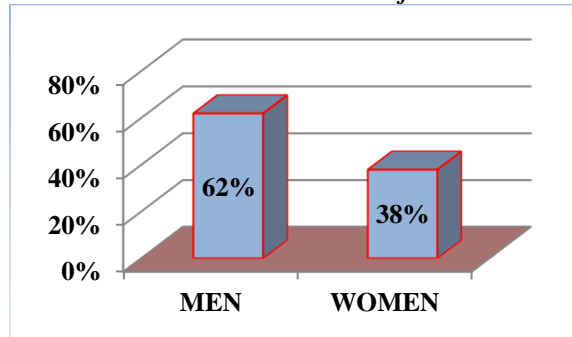
Source : Picture archiving and communication system (PACS) of Institute of Radiology, Skopje

Demographic, clinical, and radiological data were presented as mean \pm standard deviation. Student's t-test, Pearson's χ^2 , and Spearman's correlation assessed parameters. ROC curves determined prognostic ability of CT markers for right heart failure, with specificity, sensitivity, and cut-off values established.

3. RESULTS

Out of the 50 patients with radiologically confirmed APE included in the study group, 31 (62%) were male, while 19 (38%) were female. The control group comprised of the CTPA's of the same subjects after anticoagulation therapy and complete or partial resolution of emboli (Chart 1).

Chart 1: Gender distribution of the cohort



Source: Author

A statistically significant difference ($p < .05$) was evident between PAOI and nearly all examined CT markers of RHD in both the initial and follow-up CTPA examinations. The reduction in PAOI during follow-up CTPA examinations corresponded with a decrease in CT markers of RHD (Table 1).

Table 1: CT markers of RHD on the initial and follow-up CTPA's: PAOI (Pulmonary Arterial Obstruction Index), IVC (Inferior Vena Cava), RA (Right Atrium), LA (Left Atrium).

Variables	Mean Values	p- level
PAOI ₁ – PAOI ₂ (%)	54,33 \pm 28,1 – 7,14 \pm 15,3	p* = ,000
RA ₁ – RA ₂ (cm)	6,36 \pm 2,0 – 3,5 \pm 1,2	p* = ,000
LA ₁ – LA ₂ (cm)	4,78 \pm 0,5 – 4,58 \pm 0,4	p* = ,001
RA ₁ /LA ₁ – RA ₂ /LA ₂	1,33 \pm 0,4 – 0,76 \pm 0,3	p* = ,000
VCI ₁ reflux– VCI ₂ reflux [n (%)]	80 (67,23) – 25 (21,01)	$\chi^2 = 51,55$ p* = ,000

Wilcoxon Signed-Rank test, χ^2 (Pearson Chi-square), $p^* < .05$

Source: Author

A robust and statistically significant positive correlation was identified between PAOI₁ and the diameter of the RA₁ ($r = .995$, $p = .000$), as well as between PAOI₁ and the ratio of diameters of RA/LA₁ ($r = .975$, $p = .000$).

Additionally, a moderately weak and statistically insignificant negative correlation was observed between PAOI₁ and LA₁ diameter ($r = -.074$, $p = .422$) (Table 2 & Figure 4).

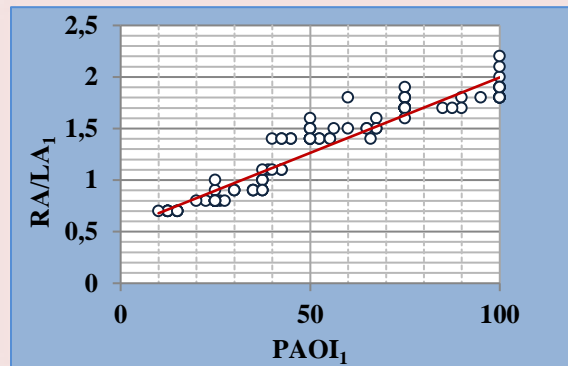
Table 2: Correlation between PAOI and other radiological parameters on the initial CTPA's; PAOI: Pulmonary Arterial Obstruction Index RA: Right Atrium LA: Left Atrium IVC: Inferior Vena Cava

	PAOI Pearson correlation coefficient (r)	p- level
PAOI ₁ η RA ₁	,995	p* = ,000
PAOI ₁ η LA ₁	-,074	p = ,422
PAOI ₁ η RA ₁ /LA ₁	,975	p* = ,000

r (Pearson correlation), $p^* < ,05$

Source: Author

Figure 4: Correlation of PAOI and the RA/LA ratio on the initial CTPA's



Source: Author

During the initial CTPA examinations, significant contrast reflux in the IVC and hepatic veins was observed in 43 (86%) subjects during the early arterial phase, with a mean PAOI value of $67.85 \pm 23.44\%$ compared to those without contrast reflux, whose mean PAOI value was $26.61 \pm 11.45\%$. A robust and statistically significant positive correlation was identified between PAOI and contrast reflux in IVC during the initial CTPAs ($r = .693$, $p < .000$), (Table 3).

Table 3: Correlation between PAOI and the IVC reflux on the initial CTPA's; PAOI: Pulmonary Arterial Obstruction Index IVC: Inferior Vena Cava

	N (%)	PAOI ₁ (mean ± SD)	p-level
VCI ₁ reflux	yes	43 (86)	$67,85 \pm 23,44$
	no	7 (14)	$26,61 \pm 11,45$

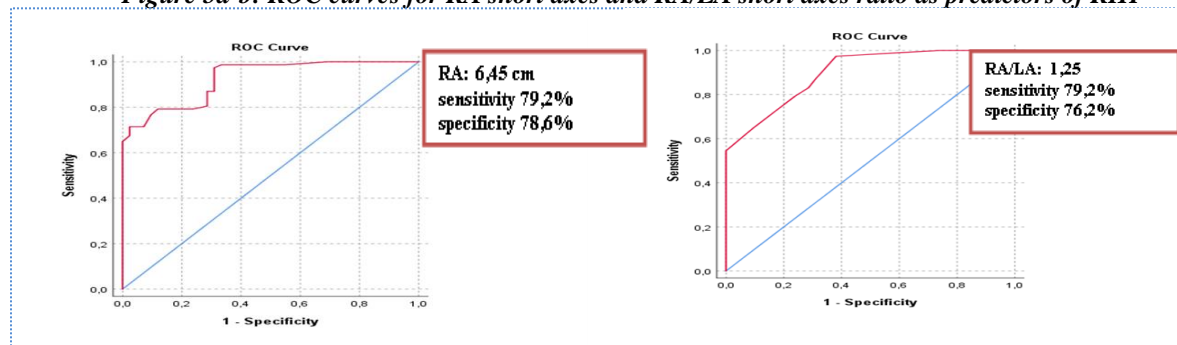
r (Point-Biserial Correlation), $p^* < ,05$

Source: Author

PAOI demonstrates exceptional predictive power for RHD diagnosis, with an AUC of 0.925 (95% CI, 0.881-0.969, $p < 0.0001$), nearing the ideal value of 1. Its sensitivity is 79.2%, specificity is 83.3%, with a cutoff value of 43.75%. The diameter of the RA, measured in centimeters (short axis), emerged as a strong predictor of RHD, with an AUC value of the ROC curve at 92.5% [AUC = 0.925 (95% CI 0.881-0.97, $p < 0.0001$)]. It demonstrates a sensitivity of 79.2% and specificity of 78.6%, with a cutoff value of 6.45 cm to predict a positive condition (Figure 5a). Analysis of the ROC curve determined that the ratio of diameters between the right and left heart atrium (RA/LA

short axes) is a robust predictor, contributing 89.9% to RHD prediction [AUC = 0.899 (95% CI 0.845-0.953, $p < 0.0001$)]. It exhibits a sensitivity of 79.2% and specificity of 76.2%, with a cutoff value of 1.25 to predict a positive condition (Figure 5b).

Figure 5a-b: ROC curves for RA short axes and RA/LA short axes ratio as predictors of RHF



Source: Author

4. DISCUSSION

Our investigation into atrial dimensions, contrast reflux in the inferior vena cava (IVC), and the pulmonary arterial obstruction index (PAOI) revealed compelling associations. Notably, a heightened burden of pulmonary arterial thrombi correlated significantly with an increased ratio of right atrium (RA) to left atrium (LA) short axes, diminished LA dimensions, and heightened right atrium short axis. These findings suggest that analyzing atrial dimensions and semi-quantitative grading of IVC reflux could aid in assessing thrombotic burden and serve as pivotal prognostic indicators for pulmonary thromboembolism (PTE).

Qanadli et al. advocate for the use of the CT pulmonary arterial obstruction index, which correlates with indices from classic pulmonary angiography, to gauge vascular obstruction due to thrombi. Their research highlights a PAOI threshold above 40% to identify patients at risk of right heart cavities dilatation, indicative of APE-related complications (Qanadli SD et al., 2001). Conversely, a PAOI below 40% suggests a lower risk of right heart failure in APE patients. Additionally, Mastora et al. propose utilizing the CT pulmonary arterial obstruction index as a quantifier for PTE severity, offering a practical scoring system for clinical use (Mastora I et al., 2003). Van der Meer et al. identify PAOI and the ratio of short axes between ventricles as predictors of fatal outcomes in hemodynamically stable APE patients (Van Der Meer RW, 2005). Few studies, albeit with limited subjects, have examined the association between PAOI, right atrial size, and IVC reflux.

Our study underscores a significant correlation between PAOI, right atrial size, RA/LA short axis ratio, and IVC reflux. These CTPA parameters could serve as effective risk stratification tools in routine clinical practice. Given the thicker ventricular wall compared to the atrial wall, arterial obstruction effects are more pronounced in atrial dimensions. Consequently, our findings suggest that right atrium dimensions, RA/LA short axis ratio, and IVC reflux grading may be sensitive diagnostic parameters for massive embolism.

5. CONCLUSION

The study has several limitations, including its retrospective nature and the limited sample size. Additionally, the lack of comparison between CTPA results and echocardiography findings, which serve as the gold standard for assessing cardiac cavity dimensions, is notable. The absence of ECG triggering during CTPA examinations posed challenges in accurately measuring heart cavity dimensions. These limitations could be addressed in the future through increased investment and the inclusion of a larger sample size to obtain more comprehensive and up-to-date information.

Measurements of PAOI, contrast reflux in the IVC, RA short axis, and RA/LA short and long axis ratio provide valuable insights into the severity of APE and serve as reliable CT prognostic markers for right heart failure development and adverse outcomes. As such, they can aid in timely diagnosis and guide appropriate therapy selection.

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