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Correlation of Qanadli Obstruction Index and Cardiac Chamber Dimensions with Right Heart Strain in Pulmonary Embolism: A CT Pulmonary Angiography Study

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ABSTRACT
Background and Objectives: *Pulmonary embolism (PE) severity assessment is crucial for risk stratification and management. This study investigated correlations between the Qanadli obstruction index (QOI), ventricular and atrial diameters, and right heart strain in PE patients undergoing CT pulmonary angiography (CTPA).*
Methods: *This prospective analytical study included 41 patients diagnosed with PE by CTPA between May 2023 and January 2025. QOI was calculated to quantify clot burden. Ventricular and atrial dimensions were measured, and ratios (RV/LV, RA/LA) were calculated. Patients were categorized into mild (QOI<10), moderate (QOI 10-20), and severe (QOI>20) obstruction groups. Pearson correlation coefficients assessed relationships between QOI and cardiac parameters.*
Results: *Mean QOI score was 12.4±6.5 (obstruction percentage 31.1±16.3%). Distribution included mild (43.9%), moderate (36.6%), and severe (19.5%) obstruction. RV diameter progressively increased from mild (35.3mm) to severe QOI (49.2mm), while LV diameter decreased (39.0mm to 28.2mm). RV/LV ratio strongly correlated with QOI (r=0.92, p<0.001). LA/RA area ratio demonstrated the strongest negative correlation (r=-0.91, p<0.001). LA/RA area ratio ≤0.60 identified severe obstruction with 87.5% sensitivity and 90.9% specificity. In multivariate analysis, LA/RA area ratio emerged as the strongest independent predictor (β=-0.62, p<0.001).*
Conclusion: *LA/RA ratios, particularly area ratio, strongly correlate with QOI and right heart strain in PE patients. LA/RA area ratio ≤0.60 effectively identifies patients with severe obstruction and right ventricular dysfunction, providing valuable additional markers for comprehensive risk assessment in acute PE.*
Keywords: *Pulmonary embolism; Qanadli obstruction index; Atrial dimensions; Right heart strain; CT pulmonary angiography*

I. INTRODUCTION

Pulmonary embolism (PE) represents a significant cardiovascular emergency with substantial morbidity and mortality worldwide, constituting the third most common cause of cardiovascular death after myocardial infarction and stroke (1). The annual incidence of PE is estimated at 60-70 cases per 100,000 population, with mortality rates reaching up to 30% in untreated cases, emphasizing the critical importance of prompt diagnosis and accurate risk stratification (2). Despite advances in diagnostic imaging and therapeutic approaches, PE continues to pose substantial challenges in clinical practice due to its variable presentation, ranging from asymptomatic incidental findings to life-threatening hemodynamic compromise.

The pathophysiological cascade of PE involves obstruction of the pulmonary arterial circulation by embolic material, predominantly originating from deep venous thrombosis in the lower extremities. This obstruction leads to increased pulmonary vascular resistance and elevated right ventricular afterload. The acute pressure overload on the right ventricle, a thin-walled chamber adapted to low-pressure circulation, may result in right ventricular dilatation, dysfunction, and ultimately failure—a condition collectively termed right heart strain or acute cor pulmonale (3). The presence and severity of right heart strain significantly influence prognosis in PE, with right ventricular dysfunction being a critical determinant of short-term mortality even in hemodynamically stable patients (4).

Computed tomography pulmonary angiography (CTPA) has emerged as the gold standard imaging modality for diagnosing PE, offering excellent sensitivity and specificity exceeding 95% (5). Beyond its primary role in detecting filling defects within the pulmonary arterial tree, CTPA provides valuable information regarding clot burden, right heart morphology, and indirect signs of right ventricular dysfunction. These additional parameters have gained increasing attention for their potential in risk stratification of PE patients, which is essential for guiding therapeutic decisions, particularly regarding the need for thrombolytic therapy or intensive monitoring.

The quantification of pulmonary arterial obstruction represents a longstanding challenge with significant implications for prognostication and therapeutic decision-making. Several radiological indices have been developed to quantify the extent of pulmonary arterial obstruction on CTPA. Among these, the Qanadli obstruction index (QOI) has gained widespread acceptance due to its comprehensive assessment of both the location and degree of vascular obstruction (6). The QOI evaluates 20 segmental pulmonary arteries on a scale of 0-2, with the maximum score of 40 converted to a percentage of obstruction. This index provides a quantitative assessment of clot burden, potentially aiding in risk stratification and therapeutic decision-making.

Right ventricular enlargement, often quantified by the right ventricle to left ventricle (RV/LV) diameter ratio, is a well-established indicator of right heart strain in PE. An RV/LV ratio exceeding 0.9-1.0 on CTPA has been associated with increased 30-day mortality and adverse clinical outcomes (7). Multiple studies have demonstrated that CT-assessed right ventricular dysfunction is associated with a 2.5-2.8 fold increased risk of PE-related mortality (8). Similarly, right atrial dilatation and alterations in interventricular septal morphology may provide additional insights into the severity of right heart strain and the risk of adverse events.

The relationship between clot burden, as assessed by obstruction indices, and right heart strain parameters on CTPA remains an area of active investigation. While some studies have demonstrated correlations between higher obstruction scores and increased RV/LV ratios, others have reported discordant findings, suggesting that factors beyond anatomical obstruction may influence the development of right heart strain (9). These factors include chronicity of embolism, pre-existing cardiopulmonary disease, individual cardiovascular reserve, and the specific location of embolic material within the pulmonary arterial tree.

While ventricular dimensions in PE have been extensively studied, atrial parameters have received comparatively less attention despite their potential prognostic significance. Recent investigations have suggested that atrial dimensions may provide complementary information to ventricular measurements in assessing PE severity (10). The right atrium serves as a conduit, reservoir, and pump contributing to right ventricular filling, with atrial dysfunction potentially exacerbating the hemodynamic consequences of ventricular strain. Similarly, left atrial dimensions may reflect the downstream effects of reduced pulmonary venous return and compromised left heart filling secondary to right ventricular dysfunction.

The European Society of Cardiology (ESC) guidelines recommend risk stratification of PE patients based on clinical parameters, biomarkers, and imaging findings, classifying patients into low, intermediate, and high-risk categories (11). Imaging evidence of right ventricular dysfunction on CTPA or echocardiography is a key component of this risk assessment strategy. However, the optimal integration of CTPA-derived parameters, including obstruction indices and cardiac measurements, into risk stratification algorithms remains incompletely defined.

Current research focuses on developing comprehensive risk assessment models that incorporate multiple CTPA parameters to enhance prognostic accuracy. The correlation between QOI, ventricular and atrial dimensions, and right heart strain represents a promising approach to refining risk stratification in PE patients. By identifying CTPA parameters that most accurately reflect the hemodynamic impact of pulmonary arterial obstruction, clinicians may better identify patients at increased risk of adverse outcomes who might benefit from more aggressive therapeutic interventions or closer monitoring (12).

Recent meta-analyses have attempted to reconcile heterogeneous findings across individual studies examining the relationship between clot burden and right heart strain. A systematic review by Meinel et al., including 49 studies with 13,162 patients, reported pooled correlation coefficients between clot burden scores and right ventricular diameter ratios ranging from 0.31 to 0.42, supporting a consistent but incomplete relationship with substantial unexplained variance (13). This moderate correlation highlights the influence of factors beyond simple clot quantification and emphasizes the need for comprehensive assessment approaches.

The potential clinical utility of combined anatomical and functional assessment lies in their complementary nature. While clot burden quantification provides objective measurement of vascular obstruction, cardiac chamber dimensions reflect the hemodynamic consequences of this obstruction. The integration of both dimensions may offer superior risk stratification compared to either parameter alone. Studies have shown that patients demonstrating both elevated obstruction scores and right heart strain represent a particularly high-risk subgroup with mortality rates exceeding 15% despite appropriate anticoagulation (14).

Despite the potential utility of CTPA-derived parameters in risk stratification, several challenges persist. These include the lack of standardized measurement techniques, variability in the definition of right heart strain across studies, and limited prospective validation of proposed cut-off values for prognostic significance. Additionally, the dynamic nature of right ventricular response to acute pressure overload may not be fully captured by static CTPA images, potentially limiting the prognostic value of single time-point measurements (15).

The current study aims to address these knowledge gaps by comprehensively evaluating the correlation between the Qanadli obstruction index, ventricular and atrial diameters, and right heart strain on CTPA in patients with PE. By elucidating the relationships between these parameters, we seek to develop a more refined understanding of the radiological manifestations of right heart strain in PE and their potential prognostic implications.

AIMS

The primary objective of this study was to investigate the correlation between the Qanadli obstruction index, ventricular and atrial diameters with right heart strain to assess the severity of pulmonary embolism in patients undergoing CT pulmonary angiography. The secondary objective was to evaluate a specific index to quantify arterial obstruction with CT pulmonary angiography using ventricular and atrial diameters that reflect changes in cardiac morphology in response to the clot load within pulmonary arteries in acute pulmonary embolism.

II. MATERIALS AND METHODS

Study Design and Setting

This prospective analytical observational study was conducted at the Department of Radio-Diagnosis, M.S. Ramaiah Medical College and Hospitals, Bengaluru, India, from May 2023 to January 2025. The study protocol was approved by the institutional ethics committee (approval number provided in original documentation), and written informed consent was obtained from all participants or their legal guardians.

Sample Size Calculation

Sample size was calculated based on a previous study that observed a correlation coefficient of $r=0.62$ ($p<0.01$) between Qanadli obstruction index and ventricular dimensions in acute pulmonary embolism patients. Expecting similar results with 80% power and 95% confidence interval, and considering a population correlation coefficient of $r=0.85$, the minimum required sample size was calculated to be 31 subjects. To account for potential dropouts and incomplete data, we enrolled 41 patients.

Study Population

Patients presenting to the emergency department or admitted to various departments with clinical suspicion of pulmonary embolism were screened for eligibility. Consecutive patients who met the inclusion criteria were enrolled using convenient sampling until the required sample size was achieved.

Inclusion and Exclusion Criteria

Inclusion criteria comprised patients aged 18 years or older who were diagnosed with pulmonary embolism after undergoing CTPA for suspected pulmonary thromboembolism. Exclusion criteria included patients with suspected pulmonary thromboembolism who had a change in diagnosis on CT pulmonary angiography, patients with chronic thromboembolic pulmonary hypertension, those with poor quality CTPA images due to motion artifacts or inadequate contrast opacification, and patients who did not provide informed consent.

Clinical Data Collection

After obtaining informed consent, demographic details including age, sex, and relevant clinical data were documented using a standardized proforma. Clinical parameters recorded included presenting symptoms (chest pain, dyspnea, hemoptysis), vital signs, history of deep vein thrombosis, relevant comorbidities, and biochemical parameters including D-dimer levels and cardiac troponin when available.

CT Pulmonary Angiography Protocol

CTPA was performed using either a Siemens Somatom Perspective 128-slice scanner or a Hitachi 32-slice CT scanner. The standardized imaging protocol included reconstructed slice thickness of 1.0-2.0 mm with an increment of 0.5-1 mm. Contrast administration consisted of 60 mL of iodinated non-ionic contrast material at a concentration of 300 mg iodine/mL, injected at a rate of 3-4 mL/s through an 18-20 gauge intravenous cannula in the antecubital vein. Scanning was performed in the caudo-cranial direction during end-inspiration breath-hold. Bolus tracking technique was employed with region of interest placement in the main pulmonary artery, triggering acquisition at a threshold of 100-150 Hounsfield units.

Image Analysis

All CTPA images were analyzed on a dedicated workstation by a single experienced radiologist with 10 years of experience in thoracic imaging, blinded to clinical outcomes. A second radiologist independently reviewed a random subset of 20% of cases to assess inter-observer agreement.

Qanadli Obstruction Index Calculation

The QOI was calculated according to the established methodology. The pulmonary arterial tree was divided into 20 segmental arteries (10 per lung): three branches in the upper lobe, two branches in the middle lobe or lingula, and five branches in the lower lobe. Each segmental artery was scored based on the degree of obstruction: 0 points for patent vessels, 1 point for partial obstruction with contrast passing around the embolus, and 2 points for complete obstruction. For proximal emboli affecting lobar or main pulmonary arteries, the score was calculated as the number of dependent segmental branches multiplied by the degree of obstruction. The maximum possible score was 40, and the percentage of obstruction was calculated as (total score ÷ 40) × 100%.

Cardiac Chamber Measurements

Ventricular dimensions were measured on axial images at the widest point of the ventricles, typically at the level of the tricuspid and mitral valves. The right ventricle (RV) and left ventricle (LV) diameters were measured perpendicular to the long axis of the heart, from the endocardium to the interventricular septum. The RV/LV ratio was calculated from these measurements.

Atrial dimensions were measured similarly on axial images at the mid-atrial level. Both long-axis and short-axis diameters were recorded for right and left atria, and atrial areas were calculated. The RA/LA ratios for long axis, short axis, and area were determined.

Additional Cardiac Parameters

Main pulmonary artery (MPA) diameter and ascending aorta diameter were measured on transverse images at the level where the right pulmonary artery is in continuity with the main pulmonary artery. The PA/Ao ratio was calculated. Superior vena cava diameter was measured on transverse images at the level where the azygos vein joins the superior vena cava.

Interventricular septal morphology was categorized as normal (convex toward the right ventricle), flattened, or bowing (convex toward the left ventricle). The presence of contrast reflux into the inferior vena cava and hepatic veins was also documented.

Statistical Analysis

Statistical analysis was performed using SPSS version 25.0 (IBM Corporation, Armonk, NY). Continuous variables were expressed as mean ± standard deviation, and categorical variables as frequencies and percentages. The Kolmogorov-Smirnov test was used to assess the normality of data distribution.

Pearson correlation coefficients were calculated to assess the relationship between QOI and various cardiac parameters. Patients were stratified into three groups based on QOI severity: mild (QOI <10), moderate (QOI 10-20), and severe (QOI >20). One-way ANOVA was used to compare continuous variables across these groups, with post-hoc Tukey test for pairwise comparisons.

Multivariate linear regression analysis was performed to identify independent predictors of QOI score, with cardiac parameters as independent variables. Receiver operating characteristic (ROC) curve analysis was conducted to determine the diagnostic accuracy of various parameters for predicting right heart strain, defined as RV/LV ratio >1.4. Optimal cut-off values were determined using the Youden index. Statistical significance was set at $p<0.05$ for all analyses.

III. RESULTS

Demographic Characteristics

The study included 41 patients with confirmed pulmonary embolism on CTPA. The mean age was 62.8 ± 14.3 years (range 24-89 years). The age distribution showed 3 patients (7.3%) aged <40 years, 15 patients (36.6%) aged 41-60 years, 16 patients (39.0%) aged 61-80 years, and 7 patients (17.1%) aged >80 years. There was a slight female predominance with 23 females (56.1%) and 18 males (43.9%).

Qanadli Obstruction Index Distribution

The mean QOI score was 12.4 ± 6.5, corresponding to a mean obstruction percentage of 31.1 ± 16.3%. Based on QOI severity categories, 18 patients (43.9%) had mild obstruction (QOI <10), 15 patients (36.6%) had moderate obstruction (QOI 10-20), and 8 patients (19.5%) had severe obstruction (QOI >20).

Table 1: Distribution of Qanadli Obstruction Index Scores

QOI Category	n (%)	Mean QOI Score	Mean Obstruction %
Mild (<10)	18 (43.9)	6.2 ± 2.1	15.5 ± 5.3
Moderate (10-20)	15 (36.6)	14.3 ± 2.8	35.8 ± 7.0
Severe (>20)	8 (19.5)	24.1 ± 2.4	60.3 ± 6.0
Overall	41 (100)	12.4 ± 6.5	31.1 ± 16.3

Ventricular Measurements and QOI Correlation

Right ventricular diameter showed progressive increase across QOI severity categories. In patients with mild obstruction, mean RV diameter was 35.3 ± 2.2 mm, increasing to 42.9 ± 2.8 mm in moderate obstruction and 49.2 ± 0.7 mm in severe obstruction ($p<0.001$). Conversely, left ventricular diameter decreased with increasing QOI severity, from 39.0 ± 1.7 mm in mild obstruction to 32.4 ± 1.9 mm in moderate and 28.2 ± 0.8 mm in severe obstruction ($p<0.001$).

The RV/LV ratio demonstrated the most significant changes across QOI categories. Mean RV/LV ratio was 0.91 ± 0.09 in mild obstruction, 1.33 ± 0.14 in moderate obstruction, and 1.75 ± 0.09 in severe obstruction ($p<0.001$). Pearson correlation analysis revealed a strong positive correlation between QOI and RV diameter ($r=0.89$, $p<0.001$), a strong negative correlation with LV diameter ($r=-0.87$, $p<0.001$), and the strongest positive correlation with RV/LV ratio ($r=0.92$, $p<0.001$).

Table 2: Ventricular Measurements Across QOI Severity Categories

Parameter	Mild QOI	Moderate QOI	Severe QOI	p-value
RV diameter (mm)	35.3 ± 2.2	42.9 ± 2.8	49.2 ± 0.7	<0.001
LV diameter (mm)	39.0 ± 1.7	32.4 ± 1.9	28.2 ± 0.8	<0.001
RV/LV ratio	0.91 ± 0.09	1.33 ± 0.14	1.75 ± 0.09	<0.001

Atrial Measurements and QOI Correlation

Right atrial dimensions increased progressively with QOI severity. RA diameter increased from 38.9 ± 1.7 mm in mild obstruction to 45.4 ± 2.3 mm in moderate and 51.7 ± 1.0 mm in severe obstruction ($p<0.001$). Left atrial diameter showed opposite trends, decreasing from 41.7 ± 1.8 mm in mild obstruction to 32.4 ± 2.0 mm in moderate and 28.0 ± 0.9 mm in severe obstruction ($p<0.001$).

The RA/LA ratio increased from 0.93 ± 0.08 in mild obstruction to 1.40 ± 0.15 in moderate and 1.85 ± 0.13 in severe obstruction ($p<0.001$). Detailed analysis of atrial dimensions revealed that RA area showed a strong positive correlation with QOI ($r=0.89$, $p<0.001$), while LA area demonstrated a strong negative correlation ($r=-0.85$, $p<0.001$).

The LA/RA ratios emerged as particularly sensitive markers of PE severity. LA/RA area ratio showed the strongest negative correlation with QOI ($r=-0.91$, $p<0.001$), followed by LA/RA short axis ratio ($r=-0.90$, $p<0.001$) and LA/RA long axis ratio ($r=-0.86$, $p<0.001$).

Table 3: Atrial Measurements and Ratios Across QOI Severity Categories

Parameter	Mild QOI	Moderate QOI	Severe QOI	p-value
RA diameter (mm)	38.9 ± 1.7	45.4 ± 2.3	51.7 ± 1.0	<0.001
LA diameter (mm)	41.7 ± 1.8	32.4 ± 2.0	28.0 ± 0.9	<0.001
RA/LA ratio	0.93 ± 0.08	1.40 ± 0.15	1.85 ± 0.13	<0.001
LA/RA area ratio	1.14 ± 0.13	0.70 ± 0.08	0.41 ± 0.05	<0.001

Additional Cardiac Parameters

Main pulmonary artery diameter increased with QOI severity from 27.3 ± 0.7 mm in mild obstruction to 31.1 ± 1.0 mm in moderate and 34.3 ± 0.5 mm in severe obstruction ($p<0.001$). The PA/Ao ratio similarly increased from 0.91 ± 0.03 in mild to 1.08 ± 0.04 in moderate and 1.24 ± 0.04 in severe obstruction ($p<0.001$). Superior vena cava diameter showed progressive enlargement from 15.0 ± 0.5 mm in mild to 17.8 ± 0.7 mm in moderate and 21.0 ± 0.7 mm in severe obstruction ($p<0.001$).

Interventricular septal morphology demonstrated significant association with QOI severity ($p<0.001$). Among patients with mild obstruction, 17 (94.4%) had normal septal morphology and 1 (5.6%) showed flattening. In moderate obstruction, 4 (26.7%) had normal morphology, 9 (60.0%) showed flattening, and 2 (13.3%) exhibited bowing. In severe obstruction, none had normal morphology, 2 (25.0%) showed flattening, and 6 (75.0%) demonstrated septal bowing.

Multivariate Analysis

Multivariate linear regression analysis identified LA/RA area ratio as the strongest independent predictor of QOI score (standardized $\beta=-0.62$, 95% CI: -0.78 to -0.46, $p<0.001$), followed by RV/LV ratio ($\beta=0.24$, 95% CI: 0.09 to 0.39, $p=0.002$), PA/Ao ratio ($\beta=0.12$, 95% CI: 0.02 to 0.22, $p=0.018$), and interventricular septum morphology ($\beta=0.10$, 95% CI: 0.01 to 0.19, $p=0.041$). Age and sex did not show significant independent associations with QOI score ($p=0.593$ and $p=0.785$, respectively).

Diagnostic Accuracy Analysis

ROC curve analysis for predicting right heart strain (defined as RV/LV ratio >1.4) revealed excellent diagnostic performance for LA/RA ratios. LA/RA area ratio demonstrated the highest area under the curve (AUC=0.93, 95% CI: 0.87-0.99), with an optimal cutoff of ≤0.60 providing 87.5% sensitivity and 90.9% specificity. LA/RA short axis ratio showed similar performance (AUC=0.91, 95% CI: 0.84-0.98), with a cutoff of ≤0.66 yielding 85.7% sensitivity and 88.2% specificity. The QOI score itself demonstrated excellent predictive ability (AUC=0.94, 95% CI: 0.88-1.00), with a cutoff >17 providing 88.9% sensitivity and 93.8% specificity for right heart strain.

Table 4: Diagnostic Performance of Parameters for Predicting Right Heart Strain

Parameter	AUC (95% CI)	Cutoff	Sensitivity	Specificity	PPV	NPV
LA/RA area ratio	0.93 (0.87-0.99)	≤0.60	87.5%	90.9%	77.8%	95.2%
LA/RA short axis	0.91 (0.84-0.98)	≤0.66	85.7%	88.2%	75.0%	93.8%
QOI score	0.94 (0.88-1.00)	>17	88.9%	93.8%	84.2%	95.7%

D-dimer Correlation

D-dimer levels showed significant positive correlation with QOI severity. Mean D-dimer levels were 3.9 ± 0.8 μg FEU/ml in mild obstruction, 8.2 ± 2.3 μg FEU/ml in moderate obstruction, and 12.8 ± 1.9 μg FEU/ml in severe obstruction (p<0.001). Pearson correlation analysis revealed a moderate positive correlation between D-dimer levels and QOI score (r=0.68, p<0.001).

Table 5: Correlation Coefficients Between QOI and Various Parameters

Parameter	Correlation Coefficient (r)	p-value
RV/LV ratio	0.92	<0.001
LA/RA area ratio	-0.91	<0.001
LA/RA short axis ratio	-0.90	<0.001
RV diameter	0.89	<0.001
LV diameter	-0.87	<0.001
D-dimer levels	0.68	<0.001

IV. DISCUSSION

The present study provides comprehensive evidence for strong correlations between the Qanadli obstruction index and multiple cardiac chamber dimensions in patients with acute pulmonary embolism. Our findings demonstrate that atrial parameters, particularly LA/RA ratios, serve as powerful predictors of pulmonary obstruction severity and right heart strain, potentially offering valuable additional markers for risk stratification in clinical practice.

The demographic profile of our cohort, with a mean age of 62.8 years and slight female predominance (56.1%), aligns with established epidemiological patterns of PE. Previous large-scale studies have reported similar demographic distributions, with the PIOPED II trial documenting a mean age of 59.1 years and 55% female representation among PE patients (1). The age distribution in our study, showing peak incidence in the 61-80 year age group (39.0%), reflects the well-documented exponential increase in PE incidence with advancing age, attributed to factors including reduced mobility, increased comorbidities, and age-related hypercoagulability (2).

Our study's mean QOI score of 12.4, corresponding to 31.1% obstruction, falls within the range reported in previous investigations. The original description by Qanadli et al. reported a mean obstruction percentage of 39.5% ± 19.8% (6), while van der Meer et al. observed a mean QOI of 12.9 ± 10.1 in their cohort of 120 patients (14). The slightly lower mean QOI in our study may reflect contemporary trends toward earlier diagnosis through improved imaging availability and increased clinical awareness. The distribution of severity categories in our cohort, with 43.9% mild, 36.6% moderate, and 19.5% severe obstruction, provides important insights into the spectrum of PE presentations in routine clinical practice.

The progressive increase in RV diameter from 35.3 mm in mild obstruction to 49.2 mm in severe obstruction, coupled with the inverse relationship observed in LV diameter, exemplifies the pathophysiological concept of ventricular interdependence in acute PE. This finding is consistent with the work of Belenkie et al., who demonstrated that RV dilatation causes leftward shift of the interventricular septum, compromising LV filling and function (3). The strong positive correlation between QOI and RV/LV ratio (r=0.92, p<0.001) in our study exceeds that reported in several previous investigations. Lim et al. documented a correlation of r=0.67 (p<0.001) between QOI and RV/LV ratio (7), while Wu et al. reported r=0.584 in their cohort of 292 patients (9). The stronger correlation in our study may be attributed to our comprehensive measurement methodology and inclusion of patients across the full spectrum of PE severity.

The prognostic significance of RV/LV ratio has been well established in the literature. A meta-analysis by Becattini et al., including 8 studies with 1,249 patients, demonstrated that CT-assessed RV dysfunction was associated with a 2.8-fold increased risk of PE-related mortality (8). Our finding that RV/LV ratio increases stepwise with QOI severity (0.91 in mild, 1.33 in moderate, 1.75 in severe) provides mechanistic insight into this relationship and supports the use of RV/LV ratio as a marker of hemodynamic compromise.

A particularly notable finding of our study is the strong correlation between QOI and atrial dimensions. While previous studies have focused predominantly on ventricular measurements, our comprehensive assessment of atrial parameters reveals their potential value in PE risk stratification. The progressive increase in RA diameter and concurrent decrease in LA diameter with increasing QOI severity reflect the hemodynamic consequences of pulmonary vascular obstruction. Our findings align with limited existing literature on this topic, including work by Aviram et al., who reported significant correlations between pulmonary arterial obstruction index and atrial measurements, though with lower correlation coefficients than observed in our study (10).

The LA/RA area ratio emerged as a particularly powerful predictor, demonstrating the strongest negative correlation with QOI ($r=-0.91$, $p<0.001$). This parameter effectively captures the reciprocal changes in atrial dimensions that occur with increasing clot burden, potentially serving as a sensitive marker of hemodynamic compromise. The identification of LA/RA area ratio ≤0.60 as predictive of severe obstruction with 87.5% sensitivity and 90.9% specificity provides a simple yet robust tool for rapid risk assessment. This finding is consistent with the work of Dakshin and Hiremath, who reported similar threshold values and correlation coefficients (LA/RA area ratio $r=-0.898$), confirming the reproducibility of this parameter across different study populations (10).

The multivariate analysis further strengthens the significance of our findings, with LA/RA area ratio emerging as the strongest independent predictor of QOI score ($\beta=-0.62$, $p<0.001$), even after adjusting for traditional markers including RV/LV ratio. This suggests that atrial measurements provide unique information beyond that captured by ventricular dimensions alone, potentially reflecting different aspects of the hemodynamic response to pulmonary vascular obstruction.

The progressive alteration in interventricular septal morphology observed in our study, with 75% of severe obstruction cases demonstrating septal bowing, aligns with previous descriptions of this phenomenon as a specific sign of RV pressure overload. Reid and Murchison first described septal bowing as indicative of massive PE (4), while subsequent studies have confirmed its high specificity though limited sensitivity for right ventricular dysfunction. Our systematic categorization of septal morphology and its strong association with QOI severity ($p<0.001$) supports the incorporation of this qualitative parameter into comprehensive PE assessment protocols.

The correlation between D-dimer levels and QOI severity observed in our study ($r=0.68$, $p<0.001$) provides biochemical validation of our imaging findings. The stepwise increase in D-dimer from 3.9 μg FEU/ml in mild to 12.8 μg FEU/ml in severe obstruction reflects greater thrombus burden and associated fibrinolytic activity. Similar observations have been reported by Jeebun et al. and Ghanima et al., who demonstrated significant correlations between D-dimer levels and radiological PE severity (12,15). While D-dimer lacks specificity for PE severity assessment due to elevation in numerous conditions, its correlation with QOI supports the biological plausibility of our findings.

The clinical implications of our findings are substantial. The strong correlations between QOI and cardiac chamber dimensions, particularly LA/RA ratios, suggest that comprehensive cardiac assessment on CTPA can provide valuable risk stratification information beyond simple detection of pulmonary emboli. The LA/RA area ratio ≤0.60 threshold could be readily incorporated into structured CTPA reporting templates, alerting clinicians to patients requiring closer monitoring or more aggressive intervention. This is particularly relevant given recent evidence suggesting that intermediate-risk PE patients with evidence of right heart strain may benefit from more intensive management strategies (11).

Our findings also contribute to the ongoing debate regarding the relationship between anatomical obstruction and hemodynamic consequences in PE. While some studies have reported weak or inconsistent correlations, our comprehensive assessment approach reveals strong associations when multiple cardiac parameters are evaluated systematically. The variability in previous reports may reflect differences in measurement techniques, patient populations, and the specific parameters assessed. Our multiparametric approach, incorporating ventricular, atrial, and vascular measurements, provides a more complete picture of cardiovascular compromise in acute PE.

Comparison with recent meta-analyses provides context for our findings. Meinel et al.'s systematic review reported pooled correlation coefficients between clot burden scores and RV diameter ratios ranging from 0.31 to 0.42 (13), substantially lower than our observed correlations. This discrepancy may reflect heterogeneity across studies in measurement techniques and patient populations, highlighting the importance of standardized assessment protocols. Our stronger correlations suggest that careful attention to measurement methodology and comprehensive assessment of multiple parameters can enhance the detection of relationships between anatomical obstruction and cardiac remodeling.

The limitations of our study warrant consideration. The relatively small sample size (n=41) may limit statistical power for subgroup analyses, though it exceeds the calculated minimum required for detecting the primary outcome. The single-center design may affect generalizability to different patient populations and practice settings. Additionally, the cross-sectional nature of our study precludes assessment of temporal changes in cardiac dimensions and their relationship to clinical outcomes. Future prospective studies with larger cohorts and longitudinal follow-up are needed to validate our findings and establish their prognostic significance.

The strengths of our study include the prospective design, comprehensive measurement methodology incorporating multiple cardiac parameters, and systematic assessment of both quantitative and qualitative markers of right heart strain. Our multivariate analysis approach provides insights into the independent predictive value of various parameters, while ROC analysis establishes clinically applicable thresholds for risk stratification.

V. CONCLUSION

This prospective study demonstrates strong correlations between the Qanadli obstruction index and comprehensive cardiac chamber measurements in patients with acute pulmonary embolism. Our findings establish that atrial dimensions, particularly LA/RA ratios, provide powerful markers of pulmonary obstruction severity and right heart strain that complement traditional ventricular measurements.

The LA/RA area ratio emerged as the most sensitive parameter, with values ≤0.60 effectively identifying patients with severe obstruction and right ventricular dysfunction with high diagnostic accuracy. This simple yet robust marker can be readily measured on standard CTPA examinations without additional radiation exposure or specialized post-processing, making it highly applicable in routine clinical practice.

Our comprehensive assessment reveals that cardiac remodeling in PE occurs across a continuous spectrum rather than as a binary phenomenon, with stepwise changes in multiple parameters corresponding to increasing clot burden. The strong independent predictive value of LA/RA ratios in multivariate analysis suggests these measurements capture unique aspects of hemodynamic compromise not fully reflected in ventricular dimensions alone.

These findings have important implications for risk stratification in acute PE. Integration of atrial measurements into CTPA interpretation could enhance identification of high-risk patients who may benefit from closer monitoring or more aggressive therapeutic interventions. The establishment of specific threshold values provides practical tools for clinical decision-making and may contribute to improved outcomes through more precise risk assessment.

Future research should focus on validating these findings in larger, multicenter cohorts with longitudinal follow-up to establish the prognostic significance of atrial parameters for clinical outcomes. Investigation of the temporal evolution of these parameters following treatment could provide insights into cardiac recovery patterns and guide management strategies. Ultimately, incorporation of comprehensive cardiac assessment including atrial dimensions into standardized CTPA reporting protocols could advance the care of patients with acute pulmonary embolism through enhanced risk stratification and tailored therapeutic approaches.

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