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Tricuspid Annular Plane of Systolic Excursion to Prognosticate Acute Pulmonary Symptomatic Embolism (TAPSEPAPSE Study)

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J.C.F. created the original study idea and assisted with manuscript drafting, editing, patient enrollment, and statistical analysis. S.L. wrote the original draft of the manuscript and assisted with patient enrollment and manuscript editing. M.T. and L.Z. prepared the statistical analysis and reviewed all patient enrollments for accuracy. M.T. also assisted in enrolling patients in the study. T.N., B.A., and G.D. prepared the discussion section of the manuscript and assisted in expanding references. S.M.L., A.S., and I.S. assisted in enrolling patients, collecting data, data analysis, and writing of the background and introduction. V.V. assisted in preparing the IRB documentation, finding original references, and writing background and methods.

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Abbreviations

CTPA, computed tomography pulmonary angiogram; ED, emergency department; EM, emergency medicine; PE, pulmonary embolism; POCUS, point-of-care sonography; RV, right ventricular; TAPSE, tricuspid annular plane systolic excursion

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Introduction—The imaging standard for evaluation of acute pulmonary embolism (PE) includes a computed tomography pulmonary angiogram. Ultrasonography has shown promise in obtaining the tricuspid annular plane systolic excursion (TAPSE) measurements, which may be of clinical importance in patients with acute PE. The objective of this study is to evaluate the diagnostic capability of TAPSE measurements for patients with suspicion for acute PE.

Methods—We prospectively enrolled patients who came to the emergency department with suspicion of acute PE. Each patient underwent a point-of-care sonogram where a TAPSE measurement was obtained, followed by computed tomography pulmonary angiogram. Based on the computed tomography pulmonary angiogram findings, patients were grouped into 3 categories: no acute PE, clinically insignificant acute PE, or clinically significant acute PE.

Results—We enrolled 87 patients in this study. Twenty-three (26.4%) of these patients were diagnosed with PE. Of patients with PE, 15 (65%) were found to have a clinically significant acute PE. Analysis of mean TAPSE measurements between patients with clinically significant acute PE and those with insignificant or no PE was 15.2 mm and 22.7 mm, respectively ($P \leq .0001$). Following receiver operating characteristic curve analysis, optimum TAPSE measurement to identify clinically significant acute PE is 18.2 mm. A cutoff TAPSE measurement of 15.2 mm shows a sensitivity of 53.3% (95% confidence interval, 26.7%–80%) and a specificity of 100% (95% confidence interval, 100%–100%) for the diagnosis of a clinically significant PE.

Conclusions—Our data suggest that TAPSE measurements less than 15.2 mm have a high specificity for identifying clinically significant acute PE.

Key Words—cardiac sonogram; point-of-care sonography; pulmonary embolism; right heart strain; TAPSE

Acute pulmonary embolism (PE) is an infrequent but potentially lethal diagnosis that is often made in the emergency department (ED). The mortality of patients diagnosed with acute PE ranges from 5% for those who are clinically stable up to 58% for patients who are in critical condition.[1–4] Overall, acute PE has a mortality of 1 in 1000 individuals in the United States each year.[5] Diagnostic testing for

these patients includes a combination of D-dimer, electrocardiogram, and diagnostic imaging. The current standard of care for the diagnostic imaging confirmation of patients with suspected PE includes a computed tomography pulmonary angiogram (CTPA) scan or ventilation-perfusion scan. CTPA, however, does not directly evaluate the right ventricle and, previous studies have explored the potential for point-of-care sonography (POCUS) to help identify evidence of right heart dysfunction, as CTPA cannot directly evaluate right ventricular pressures or function.[6]

In patients with clinically significant acute PE, arterial occlusion may create a pressure overload that leads to increased right ventricle pressure, causing right ventricular (RV) dilatation and decreased function of the right ventricle.[7] The burden of the clot occlusion can be manifested by decreased RV outflow, increased pulmonary vascular resistance, and increased RV wall stress.[4] This situation results in dilatation in the RV outflow tract and an increase in pulmonary artery pressure, which can manifest as RV dysfunction.[8–10] Patients with clinically insignificant PE may not exhibit any hemodynamic or structural cardiac changes; however, patients with a large clot burden may exhibit RV dysfunction that can be identified with sonography.

For patients with suspicion of a PE, early diagnosis of acute PE is useful to help guide management in the ED. While CTPA is currently the gold standard for making the diagnosis, there are several drawbacks, including transport time to obtain the scan, exposure to ionizing radiation, inability to scan patients with renal insufficiency, and the inability to scan hemodynamically unstable patients.[11] Given these limitations, sonography has been evaluated as an alternative, noninvasive modality to help evaluate RV function.

The tricuspid annular plane systolic excursion (TAPSE) has been studied as a surrogate measure for the assessment of RV function. This technique consists of using M-mode echocardiography, which can be used to measure the movement of the tricuspid annulus of the right ventricle between the end of systole and end of diastole.[4,12] Previous studies done on healthy individuals without an acute PE estimate the normal TAPSE value to be between 2.4 cm and 2.6 cm.[13] A lower TAPSE value represents decreased RV function.[13] TAPSE values have proven to have prognostic utility for patient outcomes and may be useful to identify patients with clinically significant RV dysfunction. Currently, several studies have evaluated the use of TAPSE for patients with acute PE; however, no previous studies have compared TAPSE values to clot burden.

The primary objective of this study is to evaluate the diagnostic capability of a TAPSE measurement for patients presenting to the ED with suspicion for acute PE. A second objective of our study is to determine the correlation between the TAPSE value and mechanical clot burden.

Material and Methods

Study Design and Settings

We performed a prospective, observational single-site study using a convenience sample of patients who presented to the ED between November 2015 and July 2017 in an urban university hospital ED, which supports an emergency medicine (EM) residency training program as well as an EM ultrasound fellowship. The annual ED census consists of approximately 57,000 patient visits with an ethnically and economically diverse patient population. The study was approved by the site institutional review board and presented following Standards for Reporting of Diagnostic Accuracy Studies guidelines.

Selection of Participants

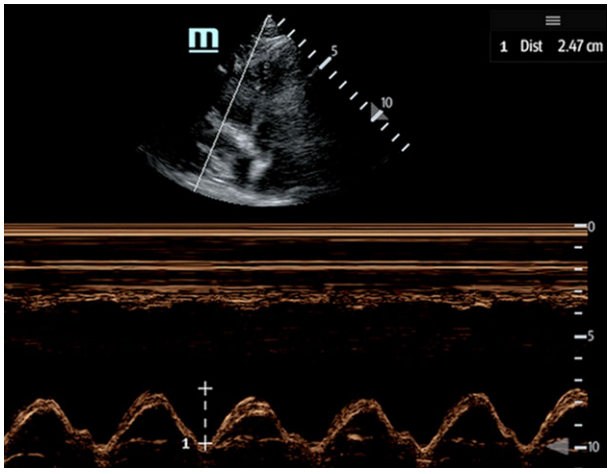
Research associates reviewed the ED grease board for potential patients daily between the hours of 8:00 AM and 12:00 midnight. Patients were eligible for inclusion if they were at least 18 years old, able to provide written and verbal consent in English or Spanish, and were undergoing CTPA for the evaluation of acute PE. All laboratory tests and imaging studies were performed at the discretion of the ordering physician. Patients were excluded if they were pregnant, incarcerated, or did not meet inclusion criteria. Patients were also excluded if they had a history of pulmonary hypertension, known pulmonary embolism, or heart failure. The research associates obtained informed written consent from eligible patients after discussion of the study with the treating physician.

Study Protocol

Research associates approached the treating physician for patients with any of the common symptoms of acute PE including chest pain, shortness of breath, syncope, or palpitations. All eligible patients with clinical suspicion for acute PE undergoing a CTPA were approached for enrollment in the study. Members of the research team approached patients and reviewed all exclusion criteria with patients prior to enrollment. Once verbal and written consent were obtained, research personal collected data using a systematic approach on a standard data abstraction sheet. Collected data included general demographics such as age, gender, and body mass index, as well as the measured echocardiographic measurements. The treating emergency physician then performed POCUS to measure the TAPSE value prior to obtaining any test results. All sonograms were performed by clinicians prior to the results of the CTPA.

We obtained TAPSE measurements using Mindray TE7 (Mindray North America, Mahwah, NJ) ultrasound machines with a phased array transducer in the cardiac setting. All patients were placed in the left lateral decubitus position to properly obtain an apical 4-chamber view of the heart. An M-mode sampling spike was placed at the right lateral border of the heart, which generated simultaneous live B- and M-mode active tracings. We obtained the TAPSE by measuring the vertical height between the peak and trough in a single cardiac cycle (Figure 1).

Figure 1. Image of M-mode ultrasound with measurement of TAPSE value. TAPSE indicates tricuspid annular plane systolic excursion.



A total of 33 unique practitioners to collected TAPSE measurements. This included EM attending physicians, resident physicians, and ultrasound fellows. Prior to the enrollment of patients in the study, all EM physicians underwent a 30-minute didactic keynote (Apple) lecture followed by supervised hands-on scanning of 3 healthy volunteer adult models. All practitioners were required to demonstrate the ability to obtain an apical 4-chamber view and correctly take a TAPSE measurement on 3 models before enrolling patients.

After the subject consented for enrollment, TAPSE measurement value was immediately obtained by the treating physician. Following this, results of the patient's CTPA were then recorded by the research associate. All POCUS images were archived and reviewed by the ED ultrasound director to confirm appropriate image quality and accurate measurements. The ED ultrasound director was blinded to CTPA results. The gold standard for the diagnosis of acute PE in this study was the presence of a filling defect in the pulmonary arteries, as reported by the attending radiologist. Radiologists interpreting the CTPA were blinded to the results of the POCUS, and EM physicians performing the POCUS were blinded to the results of the CTPA.

We grouped patients into 3 categories. The first group had no filling defects within the pulmonary arteries and were classified as negative for acute PE. The second group had small, subsegmental PEs of variable acuity without evidence of RV dysfunction on CTPA. These patients were classified as having a clinically insignificant acute PE. The third group had clinically significant acute PE, which we defined as any of the following: acute PE with large filling defects, PE located in the central location (segmental or proximal), saddle acute PE, pulmonary infarction, or computed tomographic evidence of RV dysfunction. Computed tomographic evidence of RV dysfunction included interventricular septal bowing into the left ventricle, RV enlargement, or pulmonary trunk enlargement. These findings were defined by the final attending radiologist read of the computed tomography scan.

Statistical Analysis

We summarized patient test characteristics as mean with standard deviation (SD) for continuous variables

and frequency (percentage) for categorical variables in non-PE, clinically insignificant PE, clinically significant PE, and overall. Furthermore, we used analysis of variance (for continuous variables) and the chi-square test (for categorical variables) to compare the variables among 3 groups. We used the 2-sample *t* test to compare TAPSE for PE versus non-PE and clinically significant versus clinically insignificant + non-PE. The overall difference of TAPSE among the 3 groups was examined by analysis of variance. We used the chi-square test to compare TAPSE among the 3 categories (non-PE, clinically insignificant, and clinically significant). The study was powered to a total of at least 20 patients with acute PE. This will provide 80% power to exclude a sensitivity 70% from a 95% confidence interval if the true sensitivity is 90%.

To show the predictive ability of TAPSE to distinguish among the 3 PE groups, we plotted a receiver operating characteristic (ROC) curve for each 2-group comparison and area under the curve with 95% confidence interval. The optimal cutoff was generated based on the point closest to the top-left part of the ROC curve with weighted sensitivity and specificity. Weight was determined by relative cost (r = 4) and disease prevalence, where *relative cost* means relative loss of a false negative as compared with a false positive. Sensitivity and specificity were calculated from the ROC curve based on the optimal cutoff. We also presented the 95% confidence interval of the sensitivity and specificity by the 2000 bootstrap. Point estimate of sensitivity and specificity was calculated based on the data. We then used the 2000 bootstrap to conduct the confidence interval. This included random resampling with replacement 2000 times and calculated the according ROC statistics for each resampling data.

Results

We enrolled a total of 87 patients during the study period. All enrolled patients had CTPA performed as well as POCUS. Twenty-three (26.4%) of these patients were diagnosed with a PE. Of these patients, 15 (65%) were found to have a clinically significant PE based on the aforementioned criteria. This included a large, proximal embolus, as defined by the attending radiology report, evidence of right heart strain, or pulmonary infarction. Both groups had similar baseline characteristics, and initial heart rate and blood pressure readings were similar, although patients with a clinically significant PE had substantially lower initial pulse oximetry readings (Table 1).

Comparison of TAPSE measurements between patients with PE and no PE (Figure 2, box plot) showed a mean TAPSE of 22.8 mm (SD, 4.3 mm) for patients with no PE and 17.6 mm (SD, 5.2 mm) for patients with PE, which reached statistical significance ($P = .0002$). Mean TAPSE measurements of patients with no PE, clinically insignificant PE, and

Table 1. Summary of patients' characteristics among 3 groups and overall

	Non-PE (N = 64)	Clinically Insignificant PE (N = 8)	Clinically Significant PE (N = 15)	Overall (N = 87)	*P* Value
Age, y	53 (16)	50 (19)	59 (18)	54 (17)	.392
Sex					
Female	34 (53.1%)	6 (75.0%)	7 (46.7%)	47 (54.0%)	.414
Male	30 (46.9%)	2 (25.0%)	8 (53.3%)	40 (46.0%)	
Temperature (Celsius)	36.7 (0.31)	36.9 (0.24)	36.8 (0.31)	36.7 (0.30)	.361
Heart rate	86 (21)	84 (13)	90 (20)	87 (20)	.749
Blood pressure (mm Hg)					
Systolic	133 (19)	129 (24)	136 (21)	134 (20)	.715
Diastolic	73 (14)	76 (22)	80 (15)	75 (15)	.254
Respiratory rate	20 (20)	17 (2)	18 (2)	20 (17)	.807
Pulse oximetry	97.7 (2.51)	98.7 (1.16)	96.1 (2.29)	97.5 (2.47)	.027
Weight (kg)	82.3 (21.89)	76.8 (18.38)	95.3 (31.79)	84.0 (23.93)	.109
Body mass index	29.3 (6.71)	28.1 (6.05)	33.5 (9.37)	29.9 (7.29)	.104

Values listed are mean for each category with standard deviation.
PE indicates pulmonary embolism.

clinically significant PE (Figure 3, box plot) was 22.8 mm (SD, 4.3 mm), 22.2 mm (3.1 mm) and 15.2 mm (4.4 mm), respectively. There was no substantial difference between the no PE and clinically insignificant PE groups ($P = .63$); however, a substantial difference exists among all 3 groups ($P < .0001$). An analysis of a combined group of patients with clinically insignificant or no PE (Figure 4, box plot) shows a mean TAPSE of 22.7 mm (SD, 4.2) as compared to a mean of 15.2 mm (SD, 4.4) in patients with clinically significant PE ($P \leq .0001$).

An ROC curve analysis produced an optimal cutoff of 20.3 mm to identify all patients with PE with a sensitivity of 71.9% (95% confidence interval [CI], 60.9%–82.8%) and specificity of 65.2% (95% CI, 43.5%–82.6%) (Figure 5). Using ROC analysis, we further determined that an optimal TAPSE cutoff measurement to identify clinically significant PE is 18.2 mm, which has a sensitivity of 83.3% (95% CI, 73.6%–91.7%) and specificity of 80% (95% CI, 60%–100%). A cutoff value of 15.2 mm shows a sensitivity of 53.3% (95% CI, 26.7%–80%) and a specificity of 100% (95% CI, 100%–100%) for the diagnosis of a clinically significant PE and a sensitivity of 34.8% (95% CI, 17.4%–56.5%) and a specificity of 100% (95% CI, 100%–100%) for diagnosis of any PE (Figure 6).

Discussion

Acute PE can be a potentially lethal diagnosis that is often made in the ED. Early recognition of this

Figure 3. Box plot of TAPSE among non-PE, clinically insignificant PE and clinically significant PE. PE indicates pulmonary embolism; and TAPSE, tricuspid annular plane systolic excursion.

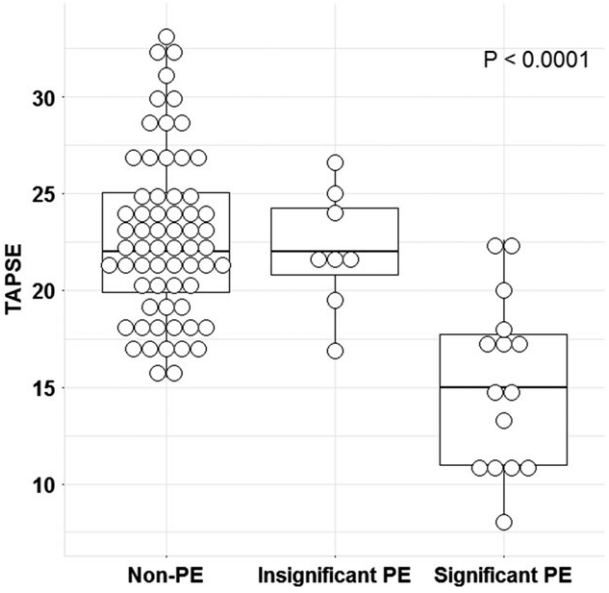


Figure 2. Box plot of TAPSE between PE and non-PE. PE indicates pulmonary embolism; and TAPSE, tricuspid annular plane systolic excursion.

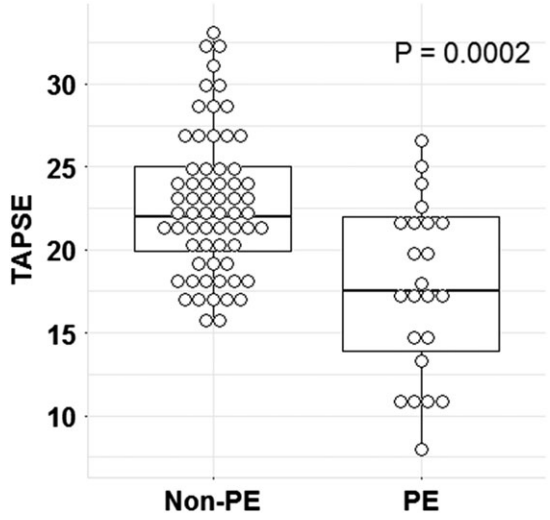
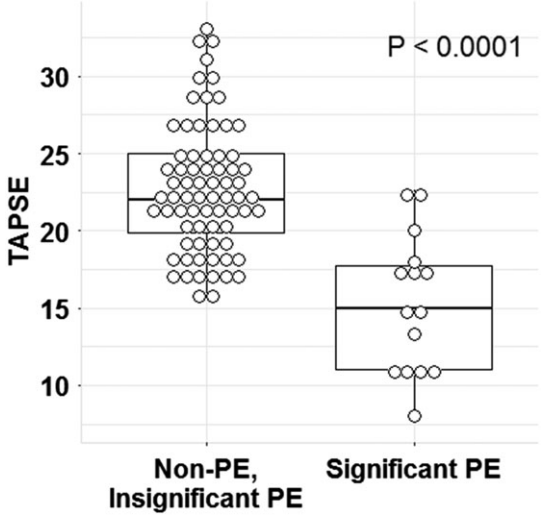


Figure 4. Box plot of TAPSE among non-PE, insignificant PE, and significant PE. PE indicates pulmonary embolism; and TAPSE, tricuspid annular plane systolic excursion.



disease can lead to interventions such as thrombolysis, anticoagulation, or clot retrieval. The current gold standard for the diagnosis of acute PE remains CTPA.[14] However, in certain populations such as pregnant women, renal impairment, contrast allergies, or hemodynamic instability, CTPA may not be suitable.[15] Increasingly, POCUS has been used to evaluate cardiac function and assess for acute PE. However, direct visualization of the pulmonary arteries is not possible with POCUS. Thus, secondary signs associated with acute PE such as RV dysfunction can be used to support the diagnosis when CTPA is contraindicated or not available. Previous studies have demonstrated that TAPSE can be used to objectively measure RV dysfunction.[13,16–18] Park and colleagues[16] and Tamborini and colleagues[19] have found a TAPSE value less than 17 mm to be indicative of RV dysfunction, which can be indicative of submassive acute PE. The aim of this study was to determine if TAPSE values can be a diagnostic indicator of right heart strain for patients with suspicion for acute PE in the ED.

In patients with clinically significant acute PE, evaluation of the right ventricle for systolic dysfunction can yield important information. Our data indicate that patients with clinically significant acute PE had an average TAPSE value of 17.6 mm, which is consistent with prior studies that correlated this value with RV systolic dysfunction. However, this historically accepted value is not specific for acute PE, and the best cutoff value for TAPSE has not been extensively examined. A recent study by Daley and colleagues[20] concluded that the optimal cutoff value for TAPSE in PE is 20 mm with a sensitivity of 72% (95% CI, 53%–86%) and a specificity of 66% (95% CI, 57%–75%). These data correspond well with our cutoff value of 20.2 mm, with similar sensitivity and specificity. In our study, the optimal cutoff value for identifying clinically significant acute PE was 18.2 mm, which yielded a sensitivity of 83.3% and specificity of 80% as compared to the optimal cutoff value for all patients with PE.

Given that 26.4% of all patients who underwent CPTA for evaluation of acute PE were found to be positive for acute PE, our data indicate that using TAPSE in conjunction with clinical evaluation and risk stratification tools such as the Well's criteria and the modified Geneva score may increase the pretest probability for diagnosis of PE. A TAPSE value below

Figure 5. ROC curve of TAPSE for PE versus non-PE. PE indicates pulmonary embolism; ROC, receiver operating characteristic; and TAPSE, tricuspid annular plane systolic excursion.

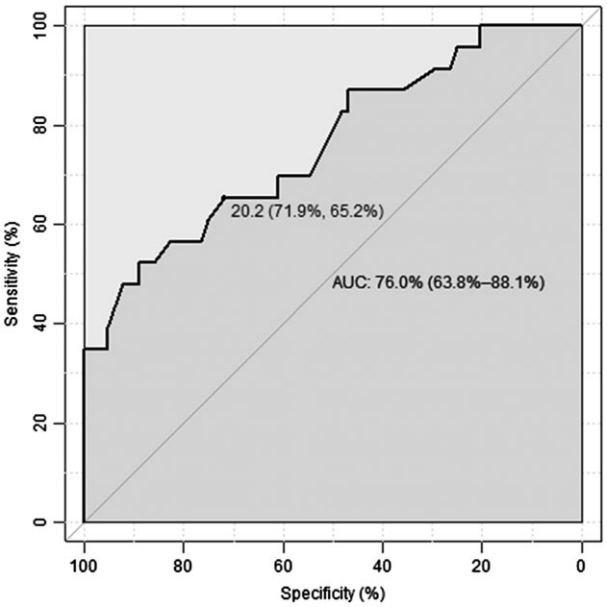
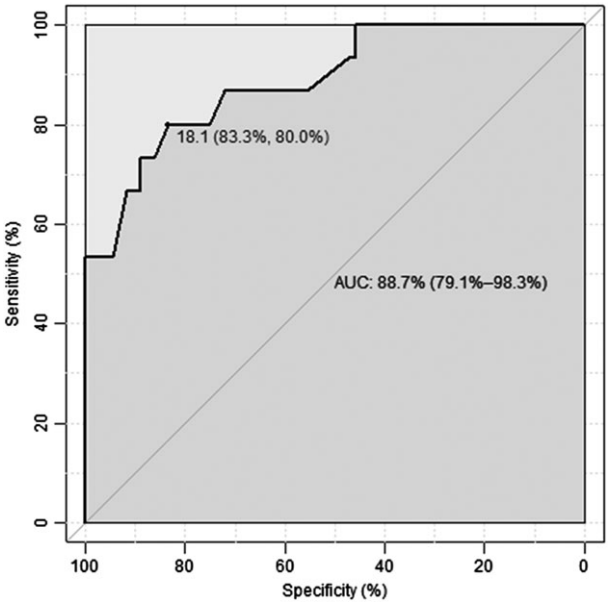


Figure 6. ROC curve of TAPSE for significant PE, insignificant PE and non-PE. PE indicates pulmonary embolism; ROC, receiver operating characteristic; and TAPSE, tricuspid annular plane systolic excursion.



the observed threshold of 18.2 mm may increase the pretest probability for acute PE. Our data show that the mean TAPSE measurements of patients with no acute PE or clinically insignificant PE were essentially the same with no statistical significance. Thus, if the presence of clinically insignificant PE is of interest to the clinician, additional imaging should be considered, as TAPSE should not be used to differentiate between clinically insignificant PE and lack of PE. For patients with clinically significant acute PE, the TAPSE value may be severely diminished. Previous studies have already shown that the higher embolic burden of PE is associated with higher mortality and increased RV dysfunction.[21–23] Thus, a finding of decreased TAPSE value in patients with high clinical suspicion for acute PE may be useful to initiate early anticoagulant therapy before CTPA and also may help obviate a closer level of monitoring such as the intensive care unit.

Based on our data, TAPSE values may be of prognostic value to stratify patients into categories based on RV dysfunction. Patients with substantially diminished TAPSE values may be at high risk for deterioration and can be candidates for fibrinolysis or clot retrieval. Conversely, patients with clinically insignificant PE and normal TAPSE values may be considered low risk and some may even be candidates for outpatient anticoagulation. Future large-scale trials are needed to continue to evaluate the role of TAPSE in the evaluation and management of acute PE. Additional studies may be useful to further validate the reliability of TAPSE measurements and compare TAPSE to cardiology-performed 2-dimensional echocardiography for the evaluation of RV dysfunction.[24]

Limitations

This study was limited by recruitment of subjects from a convenience sample of patients at a single center, which may introduce selection bias and decrease the external validity and generalizability. Our study did not seek to determine the amount of training required for proficiency in obtaining or interpreting TAPSE values. Measurements can be affected by operator experience, and we did not assess for interrater reliability in this study. Additional findings or studies such as cardiology-performed echocardiography that can suggest right heart strain such as RV dilatation, electrocardiogram, and troponin were not recorded or evaluated for study purposes. Computed tomography scan can capture only one point in time and is not the criterion standard to assess for RV dilatation. We were unable to study patients who did not undergo CPTA, including pregnant women, patients with renal insufficiency or contrast allergies, or prisoners; thus, our results may not be applied to these populations.

Conclusion

In patients presenting to the ED with clinical suspicion for acute PE, the optimal TAPSE value to assess for clinically significant acute PE is 18.2 mm. Using a cutoff of 15.2 mm, TAPSE has a sensitivity of 53.3% and a specificity of 100% for the diagnosis of a clinically significant PE. For patients with clinically insignificant PE, TAPSE may not be useful because of the lack of RV dysfunction.

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