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TRICUSPID ANNULAR PLANE SYSTOLIC EXCURSION (TAPSE) FOR RISK STRATIFICATION AND PROGNOSTICATION OF PATIENTS WITH PULMONARY EMBOLISM

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☐ **Abstract—Background: The categorization of pulmonary embolism (PE) as non-massive, sub-massive, and massive helps guide acute management. The presence of right ventricular (RV) strain differentiates sub-massive from non-massive PEs. Unlike laboratory markers and electrocardiogram changes, the classic parameters used in the echocardiographic diagnosis of RV strain have a technical component that is operator-dependent. Objective: This narrative review will describe the physiologic effects of a PE on the RV and how this affects prognosis. It will summarize the literature evaluating the accuracy and prognostic ability of tricuspid annular plane systolic excursion (TAPSE) in the echocardiographic assessment of RVfunction. The review will describe the appeal of TAPSE for this purpose, provide cutoff measurements, and then illustrate how to perform the technique itself, while offering associated pearls and pitfalls in this bedside evaluation. Discussion: RV function and dynamics undergo acute changes in the setting of a PE. RV dysfunction predicts poor outcomes in both the short and long term. However, RV strain is difficult to capture on echocardiography due to the chamber's complex geometric shape and contraction. From the apical four-chamber window, TAPSE offers a quantitative measure that is more easily performed with high interobserver reliability for evaluating systolic RV contraction. This measurement carries prognostic value in patients diagnosed with PE. Conclusions: Along with other more qualitative echocardiographic parameters, TAPSE can be used as a simple quantitative measure of RV dysfunction for differentiating sub-massive from non-massive PEs. This categorization helps guide acute management and disposition.**

☐ **Keywords—tricuspid annular plane systolic excursion; TAPSE; echocardiography; point-of-care ultrasound; right ventricle; right ventricular strain; pulmonary embolism**

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CLINICAL SCENARIOS

Clinical Scenario 1

A 55-year-old male presented to a community emergency department (ED) with chest pain and shortness of breath. He was diagnosed with a pulmonary embolism (PE) by computed tomography angiography (CTA). Vital signs were unremarkable, electrocardiogram (ECG) shows normal sinus rhythm, and troponin and brain natriuretic peptide (BNP) were normal. He felt minimal symptoms and could see his private cardiologist in the next few days. The physician considered discharging the patient with a prescription for apixaban or rivaroxaban, with strict instructions to return to the ED.

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Clinical Scenario 2

A 60-year-old male presented to an academic ED with chest pain and shortness of breath. He was diagnosed with a PE by CTA. Vital signs were notable for heart rate of 105 beats/min, ECG showed sinus tachycardia, and troponin and BNP were normal. A heparin bolus and drip were initiated. He still felt some chest pain at rest. The physician needed to determine the patient's admitting service.

INTRODUCTION

Approximately half of PEs are diagnosed in the emergency setting (1,2). PEs can be categorized into three groups based on their characteristics and in-hospital mortality rates (Table 1) (3–5). Accordingly, these characteristics are carefully defined (Tables 2 and 3).

This determination of PE classification is significant because it helps guide management. Evidence supports the use of thrombolytics for massive PE as long as there are no contraindications (3,6–9). In contrast, non-massive PEs do not warrant thrombolytics, and some may even be treated safely at home (10,11). It is for the sub-massive PE category that the evidence is less clear (4,12–16). This decision may depend on the patient's clinical course and warrants discussion with the patient and consultants.

Among the markers for right ventricular (RV) strain, only echocardiography requires technical skill for acquisition, that is, point-of-care ultrasound (POCUS). It is also the only marker to offer physiologic information on RV function. Some common imaging findings include a dilated right ventricle in the apical four-chamber (A4C) (Video 1) or parasternal long axis (PLAX) (Video 2) views; a D-shaped interventricular septum in the parasternal short axis (PSAX) view (Video 3); and moderate-to-severe tricuspid regurgitation in the A4C (Video 4) (Figure 1), PSAX, sub-xiphoid (SX) or RV inflow views. Nevertheless, image interpretation for evaluating RV strain may be variable due to operative POCUS experience and skill level (17–22).

The purpose of this narrative review is to describe tricuspid annular plane systolic excursion (TAPSE) as an easily performed and repeatable quantitative echocardiographic assessment that suggests RV strain. In patients with diagnosed PE who otherwise have hemodynamic stability, normal laboratory markers (troponin and BNP), and no ECG changes suggesting RV strain, TAPSE can be used at the bedside to differentiate sub-massive from non-massive PEs.

Table 1. Pulmonary Embolism Classification

Classification	Characteristics	In-Hospital Mortality, %
Massive	Hemodynamic instability	25–50
Sub-massive	No hemodynamic instability, but with right ventricular strain	3–15
Non-massive	No hemodynamic instability or right ventricular strain	< 5

Table 2. Definition of Hemodynamic Instability

Hemodynamic instability (defined by any one of the following):
- Sustained hypotension with systolic blood pressure < 90 mm Hg for ≥ 15 min or requiring inotropic support (not due to another cause other than pulmonary embolism)
- Pulselessness
- Persistent profound bradycardia (heart rate < 40 beat/min) with signs or symptoms of shock

METHODS

This is a narrative review summarizing the literature describing the physiologic effects of a PE on the RV, as well as the data supporting the role of TAPSE in its echocardiographic assessment. A literature review of the PubMed and Google Scholar databases was performed with search date 1950 to December 2018. Search terms included *tricuspid annular plane systolic excursion (TAPSE)*, *pulmonary embolism + TAPSE* or *echocardiography* or *ultrasound* or *point-of-care ultrasound* or *right ventricle*. The authors included studies assessing the relationship of TAPSE with RV systolic function and outcomes in patients diagnosed with PE. Experimental studies, case controls, cohort studies, and expert reviews were included, as determined by relevance to the narrative review by the authors. Commentaries and letters were excluded. Assessment of the strength of evidence was performed using the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) system.

DISCUSSION

RV Structure and Dynamics in PE

The RV has an unusual geometric shape that precludes the straightforward assessment of volume and ejection

Table 3. Definition of Right Ventricular Strain

Right ventricular strain (defined by any one of the following):
- Elevated laboratory markers
  - BNP > 500 pg/mL
  - Troponin I > 0.4 ng/mL
  - Troponin T > 0.1 ng/mL
- New electrocardiogram changes
  - Incomplete or complete right bundle branch block
  - Anteroseptal ST elevation or depression
  - Anterolateral T wave inversion
  - Right axis deviation
- Bedside echocardiography

BNP = brain natriuretic peptide.

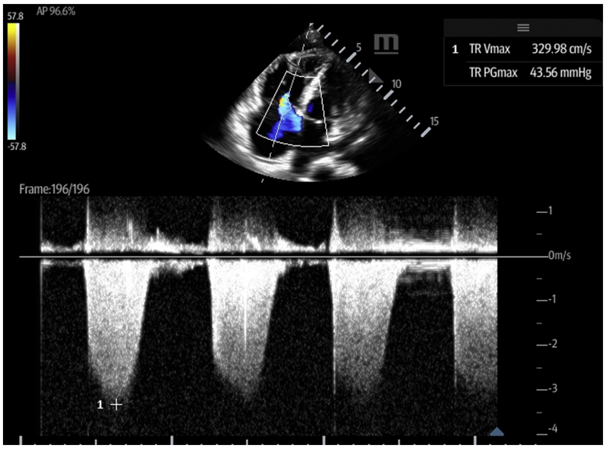

Figure 1. Moderate-to-severe tricuspid regurgitation in the apical four-chamber view using continuous-wave Doppler. The signal is dense, eccentric toward the septal wall, between parabolic and triangular, and has an early peak velocity. There also appears to be a wide vena contracta. To even further improve this assessment, the color box should be focused only over the tricuspid valve and its retrograde chamber (right atrium).

fraction. It appears triangular-shaped when viewed from the side and crescent-shaped when viewed in cross-section (23,24). Its three parts are the inlet, the highly trabeculated body, and the smooth outlet portion, known as the conus or infundibulum (25). The contraction of the RV is also a complex process. It begins at the proximal inlet and ends at the infundibulum and outflow tract. These inlet and outlet regions contract perpendicularly to each other. The RV carries superficial subepicardial muscle fibers designed for circumferential contraction and deep subendocardial fibers for longitudinal contraction, the latter of which contribute 80% of the cardiac output (10,26–28).

The RV and pulmonary arterial vasculature constitute a low-resistance, high-capacitance system. The RV is thus better able to handle increased preload than increased afterload (24). Unfortunately, in the setting of a PE, there is an abrupt increase in pulmonary vascular resistance and RV afterload. The RV cannot achieve the increased pressure needed to overcome the large clot burden and its associated mechanical obstruction. Even an obstruction of > 25–30% of the pulmonary arteries is associated with an increase in pulmonary pressures and 30% reduction in RV stroke volume (29,30). Outright RV failure may be seen when 50–75% of the pulmonary vasculature is obstructed by thrombi (29). This strain on the RV will initially lead to chamber dilation and slight leftward bulging of the interventricular septum. Together with a decrease in RV stroke volume, these changes will impair preload to the left ventricle (LV). A reduction in LV stroke volume will lead to hypotension, decreased coronary perfusion, and ischemia. As part of a worsening spiral progression, the decreased LV contractility will also lower RV contractility due to 40% of the RV contractile forces deriving from the LV (31).

Role of Echocardiography after the Diagnosis of PE

European and United States guidelines have stated that RV dysfunction and cardiac biomarker elevations are more relevant for risk stratification than the anatomic burden and distribution of pulmonary artery clots (5,32). In the short-term, RV dysfunction on bedside echocardiography can portend development of hypotension, cardiorespiratory deterioration, or death, despite the initiation of anticoagulation (33–37). In the long-term, patients treated with standard anticoagulation (and not thrombolytics) may end up with persistent RV strain and functional limitation (38,39). It is these patients who should be considered for systemic or catheter-based thrombolytics, or at least more intensive clinical monitoring and disposition.

The goal of echocardiography in cases of established PE is to identify high-risk patients and appropriately direct care before they may decompensate. Unfortunately, the RV is difficult to evaluate using bedside echocardiography due to its complex geometric shape and contractile pattern. No single echocardiographic finding or parameter (ie, RV/LV ratio > 1:1, D-shaped intraventricular septum, tricuspid regurgitation) provides a clear-cut assessment of RV systolic function.

TAPSE for Evaluation of RV Dysfunction

TAPSE has gained traction as a risk stratification and prognostic tool through its quantitative assessment of global RV function and ejection fraction. With an RV-focused

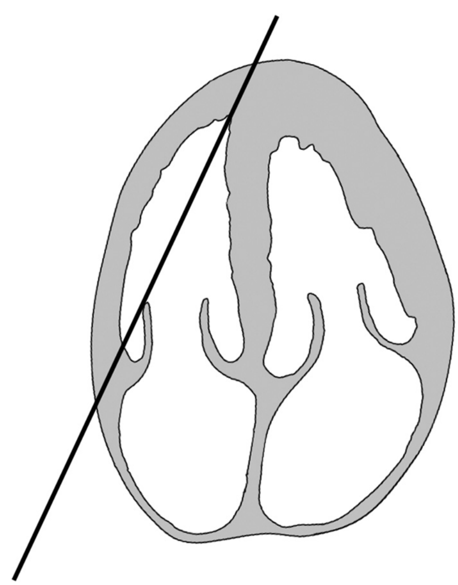

Figure 2. Depiction of how to measure tricuspid annular plane systolic excursion. In an RV-focused apical four-chamber view, the M-mode cursor is placed over the lateral tricuspid annulus.

Table 4. Cutoff Values for TAPSE in Relation to PE-Related Outcome Measures

First Author	Outcome Measure	Lower Cutoff (mm), Abnormal	Upper Cutoff (mm), Normal
Lobo (51)	All-cause and PE-related 30-day mortality	≤16	≥18
Pruszczyk (52)	PE-related 30-day mortality	≤15	≥20
Paczyńska (54)	PE-related 30-day mortality	≤15	≥18
Schmid (55)	Intraoperative CPR and death while undergoing emergent pulmonary embolectomy	<18	—
Ciurzyński (62)	PE-related mortality or need for rescue thrombolysis in initially normotensive patients at 30 days	—	>20

CPR = cardiopulmonary resuscitation; PE = pulmonary embolism; TAPSE = tricuspid annulus plane systolic excursion.

A4C view, this one-dimensional measure of RV systolic function is obtained in M-mode by measuring the vertical displacement of the lateral tricuspid annulus from the end of diastole to end of systole (Figure 2). This measurement reflects the longitudinal contraction of the RV, which constitutes 80% of the ventricle's cardiac output (10,28). Using a qualitative assessment, the TAPSE can conceivably be estimated as normal vs. abnormal based on the visualized longitudinal "bounce" of the RV (Video 5).

TAPSE has been shown to approximate RV ejection fraction with 80% sensitivity and 75% specificity (40). It has been used by cardiologists to reliably assess RV dysfunction and ejection fraction correlated with cardiac magnetic resonance imaging and right heart angiography (40–42). Using transesophageal echocardiography, the mid-esophageal four-chamber view was validated as a good correlate to RV systolic function as reflected by RV fractional area change (43). TAPSE has also been validated against RV ejection fraction calculated from the biplanar Simpson's rule, and can assess for RV dysfunction in patients with heart failure with preserved ejection fraction (44–47). Interestingly, a logarithmic relation has also been shown between high-sensitivity troponin elevations and lower TAPSE values in patients diagnosed with PE (48).

TAPSE as a Prognostic Tool in Patients with PE

The quantitative measurement of TAPSE is decreased in patients with acute PE (49,50). It is independently predictive of increased short-term mortality and increased length-of-stay in the intensive care unit (51–53). In those patients who are normotensive, it reflects RV function and independently predicts survival, while demonstrating superiority for risk stratification compared to the RV/LV ratio (51,54). TAPSE measurements can also be used to predict acute decompensation in patients undergoing acute pulmonary artery embolectomy (55). TAPSE may recover incompletely after 3 months, and is independently associated with a decreased long-term survival (49,56).

Attractiveness of TAPSE as a Measurement Tool for RV Dysfunction

To measure TAPSE, only visualization of an RV-focused A4C view is required. Acquisition of the A4C view is a basic milestone of goal-directed focused ultrasound (57,58). Additionally, unlike other more qualitative parameters of RV dysfunction, TAPSE provides a quantitative assessment. This numerical value allows an easier determination of normal compared to abnormal longitudinal systolic RV contraction. TAPSE has also been shown to be reproduced by physicians with high interobserver reliability (59–61). It may be less dependent on overall optimal image quality as well, as it only requires a high-quality view and focus of the RV.

Cutoff Measurements of TAPSE

There is no consensus measurement or cutoff value for TAPSE in offering prognostication in patients with diagnosed PE (Table 4). Nevertheless, TAPSE measurements on either extreme of the spectrum offer sufficient confidence.

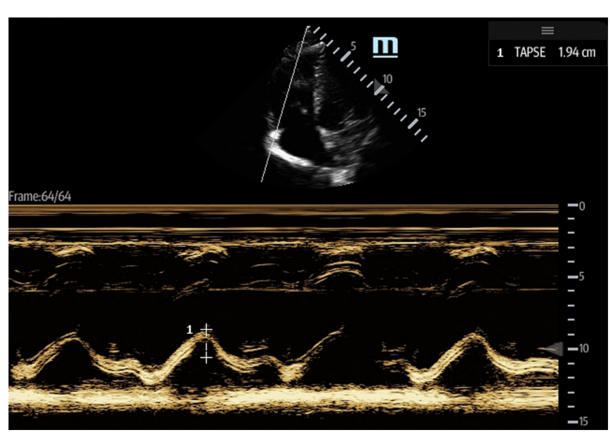

Figure 3. Normal tricuspid annular plane systolic excursion.

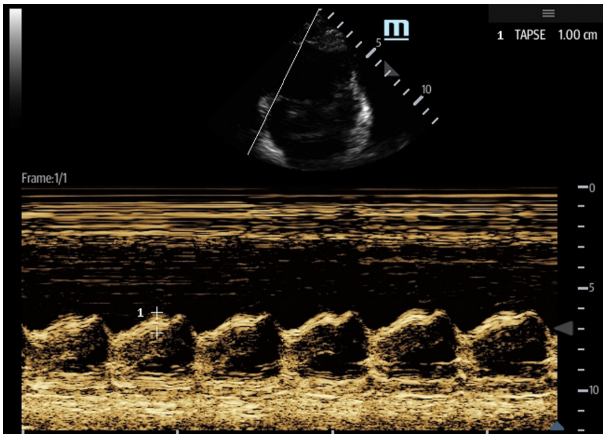

Figure 4. Abnormal or decreased tricuspid annular plane systolic excursion.

Limitations of TAPSE

TAPSE measures the longitudinal excursion of the lateral tricuspid annulus in only one dimension. It does not incorporate the transverse contribution to ejection fraction of the RV free wall and septum. For this reason, TAPSE may provide less accuracy in patients with regional variation in RV systolic function. In addition, a decreased TAPSE is not specific to PE, but rather may also result from longstanding pulmonary hypertension and congestive heart failure (59). Moreover, obtaining TAPSE requires acquiring an A4C view of sufficient quality.

How to Obtain TAPSE, with Associated Pearls and Pitfalls

1. Acquire an RV-focused A4C view of the heart (Video 1).
   a. Place the transducer at the lowest rib space feasible that acquires this view. This will ensure the proper plane of the ultrasound beam propagating through the true apex of the heart, such that the chambers are visualized at their longest. This will prevent foreshortening of the RV with subsequent underestimation of the longitudinal excursion of the lateral tricuspid annulus.
2. Place the M-mode cursor over the lateral tricuspid annulus (Figure 2).
3. Using M-mode, measure the distance of the longitudinal displacement of the lateral tricuspid annulus between end-diastole and end-systole.
   a. Measure from the top of the hyperechoic annulus signal during systole to the top of the hyperechoic annulus signal during diastole, or measure from bottom to bottom.
   b. Calculate the average of several consecutive cardiac cycles.
4. Differentiate normal (Figure 3) from abnormal (Figure 4).
   a. Refer to prior echocardiography reports or saved images for comparison if available.
   b. Be on guard for a hyperdynamic LV pulling strongly upon the RV. This may lead to a normal TAPSE measurement that masks an RV with poor systolic function.

CONCLUSIONS

TAPSE offers a quantitative assessment with high interobserver reliability for evaluating systolic RV contraction. Given the operator dependence and qualitative nature of other RV assessment parameters, TAPSE may thus serve a valuable role in differentiating sub-massive PEs from non-massive PEs based on the presence of RV dysfunction. In turn, this may direct important decisions in patients with diagnosed PE, such as disposition and administration of thrombolytics.

The strength of evidence assessed using the GRADE system was “moderate.” “High” strength evidence could be attained by randomized controlled trials evaluating the association between measuring TAPSE and prognosis in patients diagnosed with PE.

CLINICAL BOTTOM LINE

Clinical Scenario 1

The physician performed a bedside ultrasound and found a TAPSE of 13 mm. This suggested a sub-massive rather than non-massive PE. Instead of discharging the patient on an oral anticoagulant with close follow-up with his cardiologist, the physician decided to admit the patient to the hospital.

Clinical Scenario 2

The physician performed a bedside ultrasound and found a TAPSE of 12 mm. This suggested a sub-massive rather than non-massive PE. Instead of admitting the patient to a telemetry bed, the physician decided to call the step-down or cardiac intensive care unit.

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SUPPLEMENTARY DATA

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jemermed.2019.09.017.

Streaming video: Five brief real-time video clips that accompany this article are available in streaming video at www.journals.elsevierhealth.com/periodicals/jem. Click on Video Clips 1–5.

ARTICLE SUMMARY

1. Why is this topic important?

The presence of right ventricular (RV) strain differentiates sub-massive from non-massive pulmonary embolisms (PEs), which helps guide acute management. Unlike laboratory markers and electrocardiogram changes, the classic parameters used in the echocardiographic diagnosis of RV strain have a technical component that is operator-dependent.

2. What does this review attempt to show?

This review describes the physiologic effects of a PE on RV function and how this affects prognosis. It summarizes the literature evaluating the accuracy and prognostic ability of tricuspid annular plane systolic excursion (TAPSE) in the echocardiographic assessment of RV function. This review also describes the appeal of TAPSE, provides cutoff measurements, and then illustrates how to perform the technique itself, while offering associated pearls and pitfalls in this bedside evaluation.

3. What are the key findings?

RV function and dynamics undergo acute changes in the setting of a PE, and this RV dysfunction predicts poor outcomes in both the short and long term. Unfortunately, RV strain is difficult to capture on echocardiography, due to the chamber's complex geometric shape and contraction. From an RV-focused apical four-chamber window, TAPSE offers an easily performed quantitative assessment with high interobserver reliability for evaluating systolic RV contraction and prognosticating patients with diagnosed PE.

4. How is patient care impacted?

Along with other more qualitative echocardiographic assessments, TAPSE can be used as a simple quantitative measure of RV dysfunction for differentiating sub-massive from non-massive PEs. This categorization helps guide acute management and disposition.