

Echocardiographic evaluation of right ventricular systolic function: The traditional and innovative approach

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Abstract

Estimation of right ventricular (RV) performance still remains technically challenging due to its anatomical and functional distinctiveness. The current guidelines for the echocardiographic quantification of RV function recommend using multiple indices to describe the RV in a thorough and comprehensive manner, such as RV index of myocardial performance, tricuspid annular plane systolic excursion, fractional area change, Doppler tissue imaging-derived tricuspid lateral annular systolic velocity (S'-wave), three-dimensional RV ejection fraction (3D RVEF), RV longitudinal strain (RVLS)/strain rate by speckle-tracking echocardiography (STE). Among these, the last one mentioned here is an innovative and a particularly promising tool that yields more precise information about complex regional and global RV mechanics. STE was initially designed to evaluate left ventricular function, but recently it has been introduced to assess RV performance, which is difficult due to its unique structure and physiology. Many studies have shown that both free wall and 6-segment RVLS present a stronger correlation with the RVEF assessed by cardiac magnetic resonance than conventional parameters and seem to be more sensitive in detecting myocardial dysfunction at an earlier, subclinical stage. (Cardiol J 2017; 24, 5: 563–572)

Key words: echocardiography, longitudinal strain, right ventricle, speckle tracking

Introduction

The right ventricle (RV) has long been regarded as the forgotten side of the heart and little attention has been paid to its evaluation [1].

Nowadays, there is no doubt that it plays a critical role in the management of different cardiovascular diseases. Indeed, function of the RV is a strong determinant of prognosis for patients with congestive heart failure, ischemic heart disease, cardiomyopathy, pulmonary arterial hypertension and congenital heart defects [2–8]. Therefore, there is a great need to assess its function accurately.

Although the gold standard for non-invasive measurements of RV size and function is cardiac magnetic resonance (CMR) imaging [9], it is time

consuming, often not feasible in everyday clinical practice and is costly.

Hence, echocardiography is the first and frequently the only method used to evaluate the RV, as it is readily available and relatively inexpensive.

Nevertheless, echocardiographic analysis of the RV is difficult because of its complex anatomy, unfavourable position within the thoracic cavity, trabeculated myocardium which impedes clear endocardial border tracing and high dependence on loading conditions of traditional RV systolic function indices [10].

Some of these issues may be tackled by using three-dimensional (3D) or two-dimensional (2D) speckle-tracking echocardiography (STE), which are novel advanced techniques of exploration of RV function.

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Figure 1. Transversal section of the ventricles (approximately 3 cm from the apex). Note the crescent shape of the right ventricle, thin right ventricular free wall, and trabeculated myocardium (Courtesy of Paweł Jabłoński, MD and Artur Antolak, MD, PhD, Department of Pathology, Hospital of Saint Wojciech, Copernicus, Gdansk, Poland).

Anatomy of the right ventricle

The RV is the most anterior cardiac chamber, located just behind the sternum. It has a triangular shape in the coronal plane and crescent shape in the transversal plane, which makes its assessment technically much more difficult compared to a relatively predictable, ellipsoidal left ventricle (LV) (Fig. 1) [10].

The RV is habitually divided into an inflow and outflow portion. Another, more precise description of RV anatomy is that it comprises three parts: the inlet (from the tricuspid valve annulus to the proximal infundibulum), the trabeculated apical myocardium and the infundibulum (conus; from the RV outflow tract to the pulmonary valve) [11].

Moreover, the RV consists of anterior, inferior and lateral (commonly known as free) walls, each of which can also be divided into three segments: basal, mid and apical.

Its thin myocardium consists of two parts: a superficial circumferential layer, which extends to the LV, and a deep longitudinal layer, which plays a key role in global RV contraction. In contrast to the LV, the right chamber lacks a third layer of oblique fibres, thus contracts in a more base-to-apex manner [12].

Under physiological baseline conditions, the RV is smaller than its left counterpart. In echocardiography it is considered normal when it does not exceed two-thirds the size of the LV in the standard apical four-chamber view. Sonographers should remember that this assumption may be misleading in cases of LV dilatation.

Volume overload causes RV dilatation resulting in a typical view of the LV resembling the letter “D” in the parasternal short axis view, which can be observed only at end-diastole. By contrast, pressure overload produces maximal septal flattening (D-shape pattern) at end-systole or throughout the entire cardiac cycle in more advanced stages [13].

Right ventricular function

The main role of the RV is to pump blood coming from systemic venous system to the pulmonary trunk. The first contracting part is the inlet and trabeculated myocardium. Finally, after 25–50 ms, the conus contracts [14].

Normally, the RV works as a high-volume low-pressure pump. Its performance is influenced by the contraction of predominantly longitudinal fibres, as well as afterload and preload.

Additionally, RV global function depends on the heart rhythm, RV systolic synchrony, atrioventricular synchrony and ventricular interdependence (mediated mostly through the interventricular septum) [10].

Interestingly, it was estimated that 20–40% of RV volume outflow and systolic pressure results from LV contraction [15].

As far as RV dyssynchrony is concerned, it could potentially reduce cardiac output or increase filling pressures [10].

Maintenance of sinus rhythm and atrioventricular synchrony is of vital importance for RV performance especially in the presence of chronic RV failure and acute RV infarction [10, 16].

It was shown that RV dyssynchrony assessed by using 2D STE was a useful parameter of RV function and an independent risk marker in cases of pulmonary hypertension [17].

Table 1. Strengths and weaknesses of the most common right ventricular systolic function indices.

Parameter	Advantages	Limitations
TAPSE	Established prognostic value Validated against radionuclide EF Readily obtainable Reproducible Less dependent on image quality	Reflects only the longitudinal function Neglects the contribution of RVOT Not representative after cardiac surgery Angle and load-dependent
S'-wave	Comparable to TAPSE	Comparable to TAPSE
Pulsed Doppler RIMP	Prognostic value Less affected by heart rate	Requires matching for R-R intervals because calculations are performed on separate recordings Unreliable when RA pressure is elevated
Tissue Doppler RIMP	Less affected by heart rate Single-beat recording with no need for R-R interval matching	Unreliable when RA pressure is elevated
IVA	Relatively load-independent	Angle-dependent Limited normative data available Affected by age and heart rate
FAC	Established prognostic value Reflects both longitudinal and radial components of RV contraction Correlates with RVEF by CMR	Neglects the contribution of RVOT to ejection Only fair inter-observer reproducibility Requires good image quality (endocardial delineation) Load-dependent
3D RVEF	Includes RVOT contribution to global function Correlates with RVEF by CMR Reliable in postoperative state (in the absence of paradoxical septal motion)	Dependence on adequate image quality Load-dependent Time-absorbing Requires offline analysis and experience Prognostic value not established
RVLS	Angle-independent Established prognostic value Easy to perform Less sensitive to loading conditions	Vendor-dependent Neglects the contribution of RVOT No universal standard established (3 vs. 6 segments the RV) Good image quality required

3D — three-dimensional; CMR — cardiac magnetic resonance; EF — ejection fraction; FAC — fractional area change; IVA — myocardial acceleration during isovolumic contraction; RA — right atrium; RIMP — right ventricular index of myocardial performance; RV — right ventricle; RVLS — right ventricular longitudinal strain; RVOT — right ventricular outflow tract; TAPSE — tricuspid annulus peak systolic velocity

Echocardiographic parameters of RV systolic function

Estimation of RV contractility by echocardiography is a challenging task due to its unique anatomy and previously mentioned physiology. Many indices have been described as surrogate parameters of RV global systolic function.

According to current guidelines for cardiac chamber quantification [18], sonographers should use multiple acoustic windows to view the right heart pre-

cisely, from different perspectives. Moreover, there is a strong need to measure various parameters, since a single index of contractility perfectly describing RV performance does not exist (Table 1).

In everyday clinical practice, the most common and feasible indices that can be used to evaluate RV systolic function are: tricuspid annular plane systolic excursion (TAPSE), Doppler tissue imaging (DTI)-derived tricuspid lateral annular systolic velocity (S'-wave), RV index of myocardial performance (RIMP) and fractional area change (FAC).

Novel techniques, such as 3D ejection fraction (EF) and RV longitudinal strain (RVLS)/strain rate, enable us to overcome some of imperfections of traditional indices but unfortunately are not always available.

Tricuspid annular plane systolic excursion

Tricuspid annular plane systolic excursion sometimes referred to as tricuspid annular motion, is a measure of RV longitudinal function. It is typically acquired in the standard apical four-chamber view by placing an M-mode cursor on the lateral tricuspid annulus and is defined as the total systolic excursion of the RV annular segment [18, 19]. TAPSE assumes that the movement of a single segment represents the function of entire, complex 3D structure of the RV. This may be invalid in many states, such as regional RV hypokinesia [19].

Right ventricular systolic function can be significantly impaired despite normal TAPSE in some cases of severe pulmonary arterial hypertension. On the other hand, RV performance may be preserved despite reduced TAPSE, as is frequently observed after cardiac surgery [20, 21].

Moreover, this parameter is relatively load- and angle-dependent and there may be some variations in values according to cardiac translation [18, 19].

Nevertheless, TAPSE is the most frequently used index for evaluation of RV performance, since it is easily obtainable, reproducible and demonstrates both diagnostic and prognostic values in many disease states.

In patients with chronic heart failure and impaired function of the LV, a TAPSE ≤ 14 mm predicted all-cause mortality in multivariate analysis [22].

Moreover, a study by Alhamshari et al. [23] reported that TAPSE could be a reliable tool for the assessment of RV function in obese patients admitted with acute myocardial infarction. They concluded that subjects with obesity had higher TAPSE at the time of acute myocardial infarction than none-obese patients. Furthermore, the authors reported that obese patients with better RV performance developed new-onset heart failure less frequently than others.

McLaughlin et al. [24] demonstrated that children with dilated cardiomyopathy were more likely to develop RV systolic dysfunction measured by TAPSE, which was also associated with worse prognoses.

What is interesting, the main result of the Ozpelit et al. study [25] was that elderly subjects diagnosed with pulmonary arterial hypertension had a specific clinical and hemodynamic profile. They found that the indices that influence the prognosis in elderly patients were different than in young patients (e.g. TAPSE was an independent predictor of death only in the elderly group).

The normal value for TAPSE is above 16 mm [18].

DTI-derived tricuspid lateral annular systolic velocity (S'-wave)

As with TAPSE, S' reflects the function of longitudinal fibres, which play a major role in RV contraction.

S'-wave is usually obtained from the apical approach by placing a tissue Doppler cursor on the lateral tricuspid annulus or in the middle of the basal segment of the RV free wall. Care must be taken to achieve parallel alignment of Doppler beam with the direction of RV longitudinal excursion. What is more, it is essential to measure the highest velocity of the ejection waveform and not the earlier isovolumetric contraction waveform, which seems to be the most common pitfall.

Advantages and drawbacks of S' are comparable to those observed while performing TAPSE. It is simple to obtain and has prognostic data, but on the other hand, it is angle-dependent, influenced by overall heart motion and does not always correspond with global RV systolic function [18, 19].

Wang et al. [26] reported that DTI-derived S' had a stronger correlation with RVEF measured by CMR than other indices (TAPSE, FAC, myocardial acceleration during isovolumic contraction [IVA], RIMP) and the best parameter to detect RVEF $\leq 20\%$ was S' < 8.79 cm/s.

The lower reference value for pulsed tissue Doppler S' wave is 9.5 cm/s [18]. The measurement of S' wave may also be performed using color tissue Doppler, but it is not prevalent. In this case, cut-off value is low (6 cm/s), since encoded data represent mean velocities [18, 19].

Right ventricular index of myocardial performance

Myocardial performance index (myocardial performance index [MPI], RIMP, Tei index) provides information about both systolic and diastolic functions of the RV.

It is defined as the ratio of total isovolumic time divided by ejection time.

$RIMP = [isovolumetric\ relaxation\ time\ (IVRT) + isovolumetric\ contraction\ time\ (IVCT)] / ejection\ time\ (ET) = [tricuspid\ closure\ to\ opening\ time\ (TCO) - ET] / ET$ [18].

Right ventricular index of myocardial performance can be obtained using either pulsed or tissue Doppler. In pulsed Doppler method, it is important to choose beats with constant R-R intervals since calculations are performed on separate recordings [19]. This is not an issue as far as the tissue Doppler method is concerned, because here all measurements are taken from a single beat [19].

The advantage of the right-sided MPI is that it is reproducible and depends only on time intervals, which makes it possible to avoid the limitations of complex RV structure and the difficulties with obtaining satisfying visualization of the entire RV [19].

This parameter is useful in a variety of clinical aspects. It was demonstrated that in patients with impaired function of the LV (LVEF < 40%) and New York Heart Association II symptoms, pulsed Doppler $RIMP > 0.38$ predicted death from cardiovascular causes and cardiovascular hospitalization [27].

On the other hand, the MPI is load-dependent, unreliable when right atrial (RA) pressure is increased and in irregular heartbeat (atrial fibrillation) [19]. Moreover, time intervals are frequently difficult to delineate and small variations can lead to a false final value.

Pulsed Doppler-derived $RIMP > 0.43$ or tissue Doppler-derived $RIMP > 0.54$ are considered abnormal [18].

Myocardial acceleration during isovolumic contraction

Myocardial acceleration during isovolumic contraction is calculated by dividing the peak isovolumic myocardial velocity (IVV) by the time from the point of zero velocity to peak velocity during isovolumic contraction (the acceleration time) and is typically obtained using DTI at the lateral tricuspid annulus [19].

This parameter has the advantage of being a relatively load-independent index of global RV systolic performance that has proved to be useful in a variety of clinical settings, including acute pulmonary embolism [28], heart failure with reduced LVEF (as a marker of subclinical RV impairment [29]), as well as in patients after mitral valve surgery (as a more reliable measure of early recovery in RV contractility [30]).

The main limitations to IVA are that it is angle-dependent and seems to be influenced by age and heart rate.

Because of the broad confidence interval around its limits of normal, no reference value for IVA was recommended [19]. In the latest guidelines for cardiac chamber quantification [18] IVA has not been mentioned as an index of RV contractility.

Fractional area change

Fractional area change is an index of global systolic RV performance. It is a 2D surrogate for EF calculated as: $(end\text{-}diastolic\ area - end\text{-}systolic\ area) / end\text{-}diastolic\ area \times 100\%$ [18].

Right ventricular areas are obtained in the apical four-chamber view by manual tracing of RV endocardium at end-systole and end-diastole including the trabeculae in the cavity [18, 19].

This parameter provides information about both longitudinal and radial components of RV contraction, so it is not limited to a single type of motion like some of the other indices mentioned above [18].

The main limitation of this method is the commonly observed poor definition of the RV lateral wall, which may be a cause of only fair inter-observer reproducibility [18]. What is more, this technique neglects the contribution of RV outflow tract to ejection, which is crucial in a number of congenital heart diseases [18, 31].

Nevertheless, FAC proved to be an independent predictor of heart failure, sudden death and stroke in patients after myocardial infarction [32, 33].

The normal reference limit for FAC is ≥ 35 percent [18].

Right ventricular EF by 3D (3D RVEF)

Right ventricular EF is measured from 3D acquisition and defined as: $(end\text{-}diastolic\ volume - end\text{-}systolic\ volume) / end\text{-}diastolic\ volume \times 100\%$ [18].

Right ventricular EF by 3D overcomes many geometric limitations related to conventional indices of RV systolic function since it integrates both radial and longitudinal components of contraction. Moreover, this technique allows us to explore the entire right chamber including outflow track, which provides deeper insight into RV pathology.

Three-dimensional EF is a global measure of RV systolic performance, but does not directly reflect contractile function, as it rather describes the interaction between contractility and load [18].

Hence, RVEF may overestimate overall systolic performance in states with increased preload, such as severe tricuspid regurgitation or atrial septal defects [31].

Three-dimensional requires a special transducer. Images are acquired by obtaining a four to six beats full-volume data set from an RV-focused apical four-chamber view, which is analyzed using subsequent dedicated software [31].

Three-dimensional of the RV has been validated against CMR in various cardiovascular diseases [34, 35]. It can be a key player in patients after cardiac surgery, when traditional longitudinal parameters (e.g. TAPSE, S') no longer reflect global RV performance because of geometrical (decreased longitudinal and increased transverse shortening) rather than functional alterations in the RV in the post-operative period. Diminished RV function, assessed by the reduction in TAPSE and S', may potentially be related to septal damage during cardiac surgical procedures, as well as poor RV protection during cardiopulmonary bypass, intra-operative ischemia and post-operative adherence of the RV to the thoracic wall [20, 21].

The main limitations to 3D for RV evaluation are load dependency, poor image quality, arrhythmias and paradoxical interventricular septal motion [18]. As it was mentioned above, RVEF seems to be of great clinical importance in post-operative state but only in the absence of striking septal shift. In this case, RV work is done by the markedly dys-synergic septum and RVEF may be normal despite significant impairment in RV contractility [36].

Furthermore, this method is time consuming, still not widely available and requires special echocardiographic training.

According to recent guidelines, an abnormality threshold for RVEF is set at 45% [18].

Right ventricular strain and strain rate by 2D speckle tracking

This new sophisticated ultrasound method, together with 3D, overcomes the challenges encountered with conventional parameters. Nevertheless, RV strain is much easier to perform and is not excessively time-consuming, which makes it particularly useful.

What is more, compared to other indices of RV systolic function such as TAPSE, S' and RIMP, it is less sensitive to loading conditions, which was confirmed in animal studies [37].

Speckle-tracking echocardiography enables the assessment of segmental myocardial multidirectional motion-longitudinal, circumferential and radial, as well as the twist and rotation of the LV.

Until recently, the analysis of rotational and torsional dynamics has been based exclusively on CMR.

Speckle-tracking echocardiography was initially designed to evaluate LV function, but recently it has been applied to the assessment of RV performance.

As far as RV is concerned, quantification of longitudinal strain is of the utmost importance. It reflects both global and regional systolic functions and is defined as the percent change in myocardial deformation [18]. In turn, strain rate describes the rate of tissue shortening over time, usually expressed as 1/s or s⁻¹ (how fast the deformation occurs) [18].

The term "speckle tracking" suggests that this method reflects the motion of speckles, which are merged into units known as "kernels" [38]. Each kernel constitutes a kind of fingerprint which is tracked afterwards by specific software throughout the cardiac cycle [38].

Since in case of longitudinal movement myocardial fibres shorten and the distance between kernels decreases, the strain result is negative. It means that the more negative value of strain, the better RV function is.

Technically, the measurements should be performed in the RV-focused apical four-chamber view. It is recommended to use acquisition frame rates ranging from 40 Hz to 80 Hz [39]. However, since mechanical events become shorter with an increasing heart rate, relatively higher frame rates are advisable in tachycardia [40]. The focus ought to be positioned at an intermediate depth to receive the best visualization for STE and sector depth and width should be adjusted so as not to contain artifacts that resembles speckle patterns, which could distort the true value of strain [39].

Classically, the entire RV is divided into six standard segments — at the basal, middle, and apical levels of the RV free wall and septum. Graphical displays of deformation parameters for each segment are generated.

The term "global" longitudinal strain may be misleading because sometimes it is obtained by averaging values observed in all six RV segments in apical four-chamber view [41], whereas in other studies it is assessed by using only three segments of the RV free wall [42].

Septum strain is not recommended for RV global systolic assessment, as the interventricular septum contributes significantly to both RV and LV systolic function [43].

Global RV strain is not, in fact, literally “global”, because it does not reflect the performance of the entire chamber since it neglects the contribution of outflow tract and other walls of the RV to the evaluation of systolic function [44].

What is more, there is no universal standard established determining whether RV strain should be received as the mean strain from the averaged strain curve of all segments or the mean peak systolic strain measured by averaging the peak segmental values displayed by the software [44].

Although STE has many advantages over traditional parameters describing RV function, there are some major weaknesses associated with this novel technique.

First of all, it is significantly influenced by image quality, reverberation and attenuation [18]. Sonographers should pay special attention to place the reference points in the right location so as not to include the pericardium and the atrial side of the tricuspid annulus, which could influence the final result [18]. Moreover, dedicated software for RV 2D strain is not available, thus a scheme designed for speckle tracking of the LV is commonly used. Additionally, the strain values derived from vendor-specific 2D speckle-tracking software are not the same and therefore are not interchangeable [45].

Nevertheless, this promising innovative imaging modality is found to have prognostic significance under various conditions.

Guendouz et al. [46] reported that RV-2D strain was a strong independent predictor of severe adverse events in patients with chronic heart failure and might be superior to other indexes of RV systolic function.

Secondly, a study by Antoni et al. [47] reported that RV strain was a univariable predictor of worse outcomes in patients treated for acute myocardial infarction with primary percutaneous coronary intervention.

Hardegree et al. [48] found that echocardiographic assessment of RV longitudinal systolic performance by strain imaging independently predicted clinical deterioration and mortality in patients with pulmonary arterial hypertension after the institution of medical therapy.

Furthermore, Moñivas Palomero et al. [49] demonstrated that RV strain could be useful for monitoring the evolution of heart transplant recipients. They found that RV strain was significantly reduced early after heart transplant and improved progressively, reaching normal values one year after surgery.

The main result of the Focardi et al. study [50] was that free wall and six-segment RVLS had

a stronger correlation with the RVEF calculated by CMR than conventional echocardiographic indices. Between the two, the highest diagnostic accuracy and strongest correlation with the RVEF measured by CMR was observed for RV free wall longitudinal strain.

It is worth noticing that some studies prove that RV strain is more sensitive in detecting subtle myocardial dysfunction than traditional parameters in many disease states [51, 52].

In accordance with the most up-to-date version of chamber quantification guidelines [18], longitudinal RV free wall strain $> -20\%$ is likely abnormal. In this respect, it should be mentioned that pooled data were heavily weighted by a single vendor [18].

Hence, there is a great need for additional information from large studies to establish a universal standard [18] because of the lack of definite reference ranges and uniformity in software, method, and definition used for calculating RVLS.

There are some studies analysing healthy subjects with 2D STE in order to determine the normal range of RV six-segment and free wall systolic strain.

The largest study providing sex- and method-specific reference values for RVLS was conducted in 276 healthy volunteers by Muraru et al. [53]. Reference values (lower limits of normality) were as follows: (i) six-segment RVLS, $-24.7 \pm 2.6\%$ (-20.0%) for men and $-26.7 \pm 3.1\%$ (-20.3%) for women; (ii) free wall (three-segment) RVLS, $-29.3 \pm 3.4\%$ (-22.5%) for men and $-31.6 \pm 4.0\%$ (-23.3%) for women.

Moreover, it was shown that free wall RVLS was 5 ± 2 strain units (%) larger in magnitude than six-segment RVLS, $10 \pm 4\%$ larger than septal RVLS, and $2 \pm 4\%$ larger in women than in men.

Muraru et al. [53] also demonstrated that free wall RVLS from a six-segment region of interest was more feasible and reproducible than from a three-segment one.

Finally, the authors recommended that RV free wall longitudinal strain be computed by averaging peak segmental values generated by the software.

Right ventricular strain by 3D speckle tracking

Three-dimensional STE is a newly developed imaging modality that estimates cardiac deformation by analysing the motion of ultrasonic speckles in gray scale full-volume 3D images. This technique opens new opportunities since it is not

restricted to a single plane but delivers data in three orthogonal planes from the same 3D recording, which may play a crucial role in assessment of the complex nature of RV.

The first study to report on a 3D STE system specialized for the RV was conducted by Atsumi et al. [54]. The investigators, using experimental sheep studies, demonstrated that the system is reliable for RV global and segmental function assessment and provides more precise information about RV pathophysiology [54].

There are an increasing number of studies showing that 3D STE may be a convenient tool in assessing complex RV pathology more effectively.

Song et al. [55] demonstrated that 3D STE could examine subclinical dysfunction of both LV and RV at an earlier stage than 2D STE in lymphoma patients after anthracycline chemotherapy.

Moreover, Kemalöglü Öz et al. [56] concluded that in the future, 3D STE may be a useful method for early detection of biventricular systolic pathology in patients with coronary slow flow phenomenon.

There are several disadvantages of 3D STE, such as lower spatial and temporal resolution compared to 2D and motion artifacts [57].

Other parameters recommended for RV quantification

In addition to the indices of RV systolic function described previously, it is mandatory to evaluate other standard parameters such as: RA and RV dimensions, inferior vena cava size and collapse, pulmonary artery systolic pressure, and, in some cases, RV diastolic function as well as RV outflow tract dimension and RV wall thickness, when indicated.

Conclusions

Nowadays, there is no doubt that evaluation of RV systolic function is of paramount importance in a variety of clinical situations. It has been proven that RV performance is a strong predictor of cardiovascular morbidity and mortality. Nevertheless, estimation of RV contractility by echocardiography is challenging, due to its complex anatomy and physiology. Although conventional parameters have an established role in the assessment of RV systolic function, there are a number of significant limitations connected with traditional techniques. The newer advanced imaging modalities, namely 3D EF and STE, are innovative and promising methods that overcome most of the difficulties

encountered with conventional indices. STE has incremental clinical value, as it allows us to understand and assess complicated RV pathology more effectively. This novel, non-invasive and relatively readily obtainable imaging tool may play a vital role in the comprehensive evaluation of unique RV function in daily clinical practice.

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