

Assessment of Right Ventricular Function Using Echocardiography: Compared with Cardiac MR Imaging

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INTRODUCTION

In the last decades, considered contributing less significantly in cardiac diseases than its left counterpart, the Right Ventricle (**RV**) didn't attract much attention of the physicians and surgeons. The introduction of the Fontan procedure in congenital heart diseases even excluded the RV from the circulation system [1].

Because of the gradual awareness the heart diseases development mechanism, the clinicians start to regard the RV as a vital role in the management and prognosis in many cardiac diseases, such as congestive heart failure, arrhythmia, sudden cardiac death, and pulmonary artery hypertension. Moreover, RV Dimensions (**RVD**) and RV function correlated closely to symptom occurrence and to exercise capacity in many clinical conditions.

Echocardiography has been accepted as the first-line imaging modality when a patient present with suspected cardiovascular diseases due to its safety, convenience, and lower cost. With several decades' development, there has been many methods to assess the right ventricular function, including Two-Dimensional Echo (**2DE**), the time-motion mode (**M-Mode**), Pulsed Wave Doppler (**PWD**), Doppler Tissue Imaging (**DTI**), Speckle Tracking Echocardiography (**STE**), and even

three-dimensional echocardiography, which provide valuable qualitative and quantitative data for assessing the spectrum of cardiac disorders. As known for the high reproducibility, excellent endocardiac definition, and high temporal resolution, Cardiac Magnetic Resonance (**CMR**) imaging is currently considered as the noninvasive reference gold standard for comprehensive assessment of both global and regional heart function.

With aim of understanding the advantages and limitations of the echocardiography in clinical cardiovascular diagnostic and prognostic implications, in this article we focus on reviewing the role of echocardiography in assessment on RV function and make a comparison between CMR imaging and echocardiography.

THE RIGHT HEART ANATOMY

There is an obvious deference both in anatomy and mechanics between Right Ventricle (**RV**) and Left Ventricle (**LV**). Due to RV more complex anatomy and mechanics, the evaluation of its size and function is challenging.

The RV is a triangular cavity composed of an anterior, inferior, and lateral (free) wall. It is divided into three anatomy parts: the inflow, the apex, and the outflow tract (**RVOT**). Wrapping around the LV, the RV has a crescent shape in the parasternal short axis (**PSAX**) [2]. Combining the thinner walls than LV and prominent trabeculations, the RV endocardiac definition is more difficult. And the retrosternal position also hinders ultrasound waves in image resolution sometimes.

The RV also has different functional mechanics from the LV. longitudinal shortening mainly contributes to the RV contraction because of the structural intergration of myocardial fibers [3]. The most myocardial fibers' orientation is longitudinal and the circumferential layer of the mid wall develops inferiorly. The RV has a lower afterload and shorter isovolumic contraction and relaxation periods than LV. The changes in volume and pressure take more impacts in RV due to its hemodynamic environment.

ECHOCARDIOGRAPHY

Echocardiography has witnessed a significant development in technology over the last 25 years. One examination can obtain a series of structural and physiological indexes. The sonographer or physician can evaluate the RV function in detail from systolic to diastolic, global to regional, physiology to pathology, one-dimensional to real-time three-dimensional [4].

M-mode echocardiography detect fast moving ventricle structure with the accurate depiction and high temporal resolution. Doppler echocardiography, (including spectral Doppler and color Doppler imaging) can measures the blood flow's direction, velocity, amplitude, and timing. 2D Transthoracic Echocardiography (**TTE**) is the footstone in the RV visual evaluation. The 3DE and STE are the novel echocardiographic approach of the RV.

As the first choice of patients with suspected cardiovascular disease, echocardiography gives an integrative approach using a combination of parameters to systematically assess the function of the RV as follows:

Two-Dimensional Echocardiography

Two-Dimensional Echocardiography (**2DE**) can measure the RV volume and RV Eject Fraction (**EF**). Calculating RV volume in 2DE demands significant geometrical assumptions and the most popular assumption is the biplane Simpson's method. The RV areas were usually measured in an apical four-chamber view. In order to calculate the EF, the end-diastolic and end-systolic frames of the RV is depicted carefully by hand. Although 2DE-derived RV EF well correlates with CMR-derived RV EF [5], this method isn't in common use than before due to unreliable accuracy [6]. It's limitations includes inferior endocardiac depiction, narrow acoustics windows, and the shape assumptions.

Additionally, the RV Fractional Area Change (**FAC**) can also be measured on the axial four chamber view by 2DE. RVFAC is the result from the difference of the RV between end-diastolic and end-systolic area divided by the end-diastolic area and multiplied by 100. And E.V. some researches show the good correlation between RVFAC and RVEF measured by CMR [7] and the lower reference of FAC is 35% [7-8].

The Time-Motion Mode Echocardiography (M-Mode)

Tricuspid Annular Plane Systolic Excursion (**TAPSE**) is a definition in the M-mode that the total excursion of the tricuspid annulus from tele-diastole to end-systole. TAPSE provides the RV systolic function information in the patients' diagnosis and the follow-up.

TAPSE is a load- and angle-dependent parameter and complies with cardiac translation. It is obtained easily and fast, less dependent on image quality than FAC, and is the least user-dependent. Moreover, TAPSE presents an excellent correlation with RVEF detected by CMR [9].

However, TAPSE only reflect basal part of the RV free wall's movement in longitudinal direction. If regarding it as an indication of the global RV function, the extrapolation disregards the contribution of the other walls in the RV contraction. In addition, the TAPSE is an extracardiac parameter, it doesn't take the rotational and translational motion of the heart into consideration. Thus, it's not appropriate to use TAPSE to assess the RV function of the patients after cardiac surgery [10].

Doppler Tissue Imaging (DTI)

Pulsed and color Doppler Tissue Imaging (**DTI**) can both acquire myocardial systolic excursion velocity (**S'**). It is obtained at the lateral tricuspid annulus or at the basal segmental level of the RVFW in the A4C view. And pulsed DTI has the higher temporal resolution than color DTI in the clinical practice. S'measurement requires heart rate between 70 bpm to 100 bpm. It's a load-

dependent parameter and the lower reference limit with pulsed DTI is 9.5 cm/s [11]. S' presents the RV systolic function with reliability and reproducibility, and it shows a correlation positively with RVEF calculated by CMR [12].

Dividing the peak isovolumic myocardial velocity by the time of peak velocity can gain myocardial Isovolumic acceleration (**IVA**). The position of measurement is at the lateral tricuspid annulus. IVA is a load-independent index of global RV systolic function, and its lower reference limit is set at 2.2 m/s². IVA is not routinely acted as a parameter for assessment of RV systolic function, but it has correlated positively with the severity of illness in many pathology conditions, including obstructive sleep apnea, mitral stenosis, and repaired tetralogy of Fallot [13].

TDI can also detect RV myocardial deformation such as strain and strain rate. Although TDI strain is independent of specific geometrical assumptions, the angle-dependence of DTI, thin myocardial wall of the RV brings challenges in the accuracy and reproducibility of measurements. Even the age and heart rate can take a significant affection in the quantification [14].

Three-Dimensional Echocardiography (3DE)

The introduction of Three-Dimensional Echocardiography (**3DE**) opens a new era of the RV echocardiographic imaging. This technology slices the RV into multiple coronal views and analyzes the images with the dedicated software. Therefore, 3DE can acquire the detail information of the anatomy components (inflow, outflow, and apex) in the RV without geometrical shape assumptions, which increases the accuracy of the measurement vastly (Figure 1).

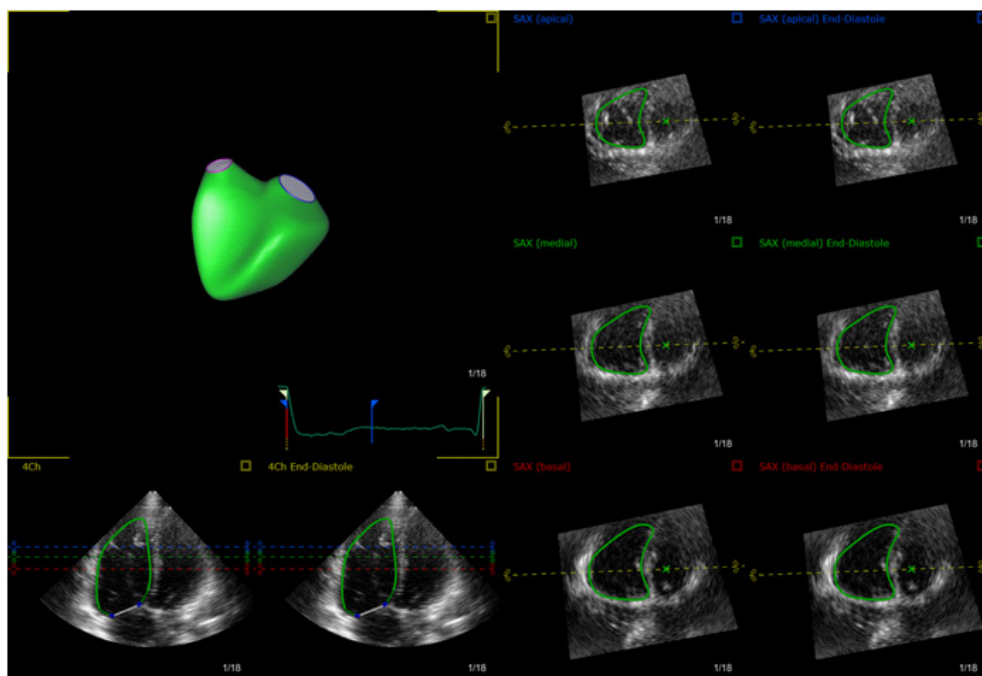


Figure 1: Assessment of right ventricle function with 3DE.

Compared with 2DE, 3DE allows a better structural depiction of the cavity and offers a more reliable detection of the RV volume and EF [15-16]. With the application in patients in different situations, 3DE has a high reproducibility in assessment of different RV size and function, and its results correlated positively with the CMR [17-18]. With the help of the mapping of endocardial surface, RV volumes calculated by have proven to be accurate and reproducible EF in comparison with CMR in different ages [19-20], only underestimation the RVEF in older patients a little bit. A current large sample meta-analysis included 807 examinees reports that there is an underestimation of larger RV volumes and an overestimation of RV volumes in older patients [23].

In the clinical settings, the clear recognition of the endocardial border in tomographic view is the key to obtain the accurate analysis of the RV. 3DE still has its limitation such as: poor image quality in patient with extensive cardiac dilation, dependence on the normal heart rhythm and subjects' cooperation [24].

Speckle Tracking Echocardiography (STE)

Speckle Tracking Echocardiography (**STE**) is no doubt a striking advance in the echocardiography technology. During the cardiac cycle, STE tracks the “speckle pattern” of amyocardial segment. With the ability to obtain the myocardial strain in deferent directions, STE provides the accurate quantification of the regional and global RV function [25]. Thus, the independence of the cardiac translation overcomes the conventional echocardiography's angle- and load-dependent limitation.

Myocardial strain is the unit change in length of an object relative to its original length. The strain reflects the myocardial function; the clinical and prognostic value of the RV strain was significant. Patients with pulmonary hypertension, heart failure and LV assist devices, congenital heart diseases, myocardial infarction, storage diseases, and cardiomyopathies with high risk of malignant ventricular arrhythmias [26-32], all can show abnormal changes in strain. What's more, Global Longitudinal Strain (**GLS**) is the most currently applied in RV assessment of a series of RV disorders [33]. RV GLS produced excellent correlation with CMR calculated RVEF and may reflect the RV systolic function [34].

The detection of the strain is acquired by tracking the endocardium border manually or automatically with the dedicated software. The analysis was dividing the RV into 6 segments (including basal free wall, mid-free wall, apical free wall, basal septum, mid septum, and apical septum). Comparing the remove of the speckles with the ones nearby throughout the cardiac cycle can obtain the strain. RV GLS is the average quantification of all 6 RV segments strain in the whole cardiac cycle.

As a new field of echocardiography, strain detection is lack of standardizations in the measurement and different echocardiographic systems may bring variability even in the same parameter acquirement. 2D STE sometimes loses the speckle of the RV lateral wall due to its excessive motion. Development of 3DE STE enables sonographer to evaluate the RV mechanics

in different dimensions similar to CMR (longitudinal, radial, circumferential and a combination of longitudinal and circumferential shortening). Although it reported that there is a good reproducibility (correlation coefficients 0.7-0.9) for strain derived by 3D STE, the deviations of estimate on different RV walls differ from 12% to 44.2% [35]. And the reliable references of the normal RV strain are required to be perfected with more populations enrolling into the investigation. It still needs efforts and time to put this index into the use of clinical settings.

RV Diastolic Function

RV diastolic function is a marker of early or subtle global RV dysfunction. The RV diastolic dysfunction places the component in many situations, such as post operation of congenital heart diseases, myocardium fraction, and it often precedes systolic dysfunction. It is vital to acknowledge that the assessment of RV diastolic function is beneficial for the patients' clinical treatment and management.

With the exploration of decades, echography has developed many indexes to evaluate the RV diastolic function. PWD provide the information with tricuspid valve inflow velocities, Peak peak early velocities (E), late diastolic velocities (A), their ratio(E/A) and the E deceleration time. DWI can assess the lateral tricuspid annulus early filling velocity (E'), lateral tricuspid annulus motion, abnormal Right Atrial (**RA**) area or volume and abnormal flow pattern in the hepatic veins, which also indicate the RV diastolic dysfunction.

The developments of CMR tagging and tissue tracking have attracted the interests in the LV diastolic function on cardiac CMR imaging: Phase-contrast CMR imaging detects mitral inflow, pulmonary venous flow; Gradient echo CMRI assesses Peak filling rate, time to peak filling rate from time-volume curve; And CMR Tagging measures LV untwisting during diastole. Although there are some control studies about the correlation of LV diastolic dysfunction between the CMR and echocardiography [36-37]. But a limited studies concentrate on RV diastolic function between the two modalities.

CMR IMAGING

CMR imaging can assess RV structure and function by providing the 3D volume images without geometric assumption. Nowadays, CMR is regarded as the “gold standard” to detect the RV anatomy and function information due to its high tissue resolution, elite endocardium definition [38].

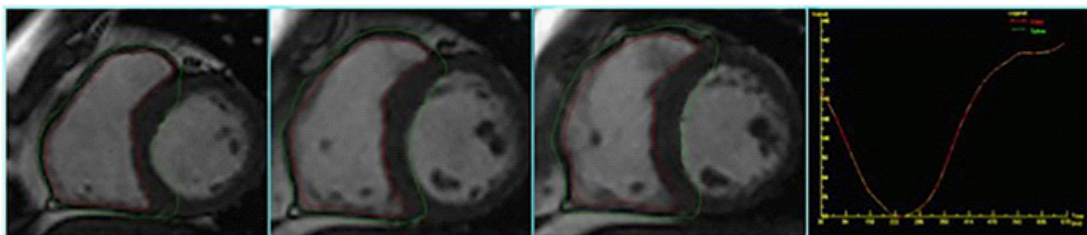


Figure 2: Right function measured by cardiac magnetic resonance imaging.

RV volumes and EF are the common parameters to indicate the global RV function. Especially, RVEF presents the RV systolic function and is an independent predictor of cardiovascular morbidity and mortality [39-41]. In recent years, the emerging of new techniques, such as CMR tagging, tissue tracking, and time-volume curve, the researchers start to explore the CMR's worth in the diastolic function assessment.

In the RV morphological evaluation, T1-weighted black-blood turbo spin-echo sequence or the Steady State Free Precession sequence (**SSFP**) is most routinely used in the clinical practice. They provide not only the images of RV but also the information of pulmonary vessels, aorta, and systemic veins (Figure 2). In order to acquire the breath-hold images, patients required a breath holding for 5-10 seconds. The clear definition of the boundaries near the RVOT and right locating of the basal tomographic plane is vital to the accuracy of the RV volume measurement.

CLINICAL APPLICATION

RV dysfunction may be caused by congenital heart disease, pulmonary hypertension, valvular heart disease, or in patients with left-sided heart failure. In critical settings, RV dysfunction is usually associated with pulmonary embolism, right ventricular infarction, severe Acute Respiratory Distress Syndrome (**ARDS**), and even septic shock [42-44]. Although assessment of RV function is challenging because of the right ventricle's complex geometry, RV function is increasingly being recognized as an important and powerful diagnostic and prognostic tool in these cardiovascular diseases. Above-mentioned improvements of echocardiography and CMR imaging provide new opportunities for accurate and noninvasive assessing RV anatomy and function [25]. Such imaging approaches may further benefit for early diagnosis of impending RV dysfunction and promptly making therapeutic decisions.

CONCLUSION

As first-line choice, echocardiography has its particular advantages for assessing right ventricular function, such as portable size, moderate price, fast imaging acquirement, exception of radiation portability, and the ability to examine patients with pacemakers and defibrillators [45]. It also has deferent methods and indexes to assess the right heart global function in deferent point of views from load, time to geometry. Moreover, echo has the potential to provide more vital cardiovascular information including RV global function in the future, with the better software and new detecting revolution. However, echocardiography has its inherent weakness when compared with the CMR, such as low definition and reproduction. If necessary, CMR can be used as an alternative modality for RV function assessment with high accuracy and reproducibility.

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