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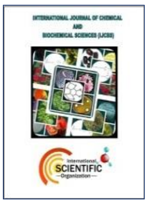

Role of Tricuspid Annular Plane Systolic Excursion in Echocardiographic Evaluation of Right Ventricular Systolic Function

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Abstract

Tricuspid annular plane systolic excursion (TAPSE) is measured using M-mode echocardiography in the apical four-chamber view to generate an image that illustrates the systolic longitudinal displacement of the lateral tricuspid annulus toward the apex. Because the septal attachment of the tricuspid annulus is relatively fixed, the major component of longitudinal systolic motion occurs at this point. The greater the displacement, the better is right ventricular function—a value less than 16 mm is considered abnormal. TAPSE correlates closely with right ventricular ejection fraction (RVEF) measured by radionuclide angiography, the "gold standard" modality for assessment of right ventricular function. TAPSE, described in 1984 as an echocardiographic measure of RV function, has been proposed as a method to overcome difficulty delineating the endocardium of the RV and avoiding geometric assumptions. TAPSE is defined as the distance of systolic excursion of the RV annular segment along its longitudinal plane measured from the tricuspid lateral annulus. Multiple studies have confirmed the correlation of TAPSE with RVEF in echocardiography, cardiac MRI and cardiac computed tomography (CT) angiography (CTA), including biplane Simpson RVEF disk summation method and fractional shortening area.

Keywords: Tricuspid annular plane systolic excursion, Echocardiographic, Right Ventricular Systolic Function

Full length article

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1. Introduction

For many years, the right ventricle (RV) was considered less relevant in cardiac diseases than its left counterpart, and was regarded as the neglected or forgotten chamber of the heart. However, the role of the RV in the management and prognosis of many cardiac diseases, such as congestive heart failure, arrhythmia, and sudden cardiac death, is increasingly recognized [1]. The position of the RV within the thorax, along with its complex structure and contraction pattern, all pose additional challenges to echocardiography. The RV is the most anteriorly positioned cardiac chamber, located immediately behind the sternum. It is thin-walled with prominent trabeculations and a complex geometry. Under normal loading conditions, the RV has a triangular shape when viewed from the side, and a crescentic shape in the sagittal plane, wrapping around the conical left ventricle [2]. The RV is a thin-walled, crescentic-shaped chamber that is coupled to the low pressure pulmonary circulation. The muscle fibers in the RV are generally aligned in two layers; a superficial layer arranged circumferentially and a deeper longitudinal layer. Due to this arrangement, the RV has a more limited contractile motion, usually seen as longitudinal shortening rather than the wringing, torsional contraction of the LV. Because the adult RV wall thickness is considerably less than LV wall thickness, the RV is more load-dependent and acutely, even modest increases in pulmonary vascular resistance (PVR) can result in significant declines in RV cardiac output. However, with chronic pressure overload (i.e., pulmonary hypertension) RV remodeling and hypertrophy can occur as an initial adaptive response that precedes RV thinning and failure [3].

2. Methods of Assessment of the Right Ventricle by 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]. A comprehensive evaluation of the right ventricle (RV) by echocardiography is essential for the diagnosis and management of conditions affecting the right heart. Indices of right ventricular size and function are prognostic in a range of congenital and acquired diseases of both left and right heart etiologies [2].

2.1. Qualitative assessment of the right ventricle

The initial approach is usually based on a visual estimate, allowing evaluation of the RV size and geometry. A rough estimate of the RV size is based on a comparison with the LV size, when the LV has a normal size, as follows: RV size is considered normal when it is less than two-thirds of the LV, mildly enlarged when it is more than two-thirds but inferior to the LV, moderately enlarged when it is roughly equal to the LV size, and severely enlarged when it is superior to the LV [5]. Examination of the septal motion in the parasternal short- axis view (PSAX) at the level of the papillary muscles may help to distinguish volume from pressure overload. RV volume overload produces RV dilatation with septal flattening (D-shaped pattern) at end-diastole, whereas pressure overload produces maximal septal flattening at end-systole [6].

2.1.1. Different views are used to assess accurately the various segments of the RV

The parasternal long-axis view (PLAX) to assess the anterior wall of the right ventricular outflow tract (RVOT); the basal PSAX to assess the inferior wall of the RV and the anterior wall of the RVOT; the PSAX at the papillary muscles level to assess the inferior, lateral, and anterior wall of the RV; apical four chamber view (A4C) to assess lateral wall; the subcostal long axis to assess inferior wall; and parasternal RV inflow view to assess anterior and inferior walls [2].

2.2. Quantitative assessment of the right ventricle

2.2.1. Linear Measurements

The RV structure is more trabeculated than the LV structure. Also, the RV has an average wall thickness of 3–5 mm in the normal adult population; RV hypertrophy is defined as a thickness of the RVFW more than 5 mm (A4C view) [7]. Quantitation of RV dimensions is critical and reduces inter-reader variability compared with visual assessment alone [8]. The most practical linear diameter used in clinical practice is the right ventricle dimension 2 (RVd2) mid-cavitary diameter taken in A4C view, and the upper normal limit is 35 mm. RV end-diastolic area is measured using the A4C or the modified A4C view; manual tracing is made by tracking the endocardial border at end-diastole and at end-systole, with trabeculations and papillary muscles included in the cavity. The current reference ranges for end-diastolic area, indexed for BSA and sex, are as follows: 5.0–12.6 cm2/m2 for men and 4.5–11.5 cm2/m2 for women [9].

2.2.2. Volumetric dimensions

Calculating RV volume in two dimensional echocardiography (2DE) requires significant geometrical assumptions and is thus prone to estimation errors; three dimensional echocardiography (3DE) allows measurements of RV volumes without translation of diameters and areas, thereby overcoming the limitations of 2DE [10]. During measurement, it is important to manually define end-diastolic and end-systolic frames. Also, myocardial trabeculae and papillary muscles should be included in the cavity. Recent published data cited the upper normal limits of indexed RV volumes as follows: RV end-diastolic volume of 87 mL/m2 in men and 74 mL/m2 in women, and RV end-systolic volume of 44 mL/m2 in men and 36 mL/m2 in women [9]. Even though 3DE tends to underestimate RV volumes compared with cardiac magnetic resonance (CMR) [11]. 3DE has identified relationships between RV volumes and EF to age and gender, which are very similar to those described by CMR [12]. Overall, women have smaller 3D echocardiographic RV volumes, despite indexing to BSA, and higher EFs. Also, older age is associated with smaller volumes, expected decrements of 5 mL/decade for end diastolic volume (EDV) and 3 mL/decade for end systolic volume (ESV) and higher EF (an expected increment of 1% per decade) [13].

2.2.3. Right ventricular systolic function

Accurate evaluation of the systolic function of the RV is better achieved by measuring one or many echocardiographic indices, and an integrative approach using a combination of parameters is preferred. These parameters comprise the tricuspid annular plane systolic excursion (TAPSE), Doppler tissue image (DTI) derived tricuspid lateral annular systolic velocity wave (S’), fractional length shortening, fractional area change (FAC), RV index of myocardial performance (RIMP), RV dp/dt and right isovolumic myocardial acceleration (IVA) [14].

2.2.4. Tricuspid annular plane systolic excursion (TAPSE)

TAPSE is defined as the total excursion of the tricuspid annulus from tele-diastole to end-systole, and it is measured typically at the lateral annulus using M-mode. TAPSE is a reliable, sensitive, and reproducible index for the initial diagnosis and for the follow-up of RV function. Moreover, it presents an excellent correlation with the RV ejection fraction (RVEF) as calculated with radionuclide ventriculography or magnetic resonance [15].The normal value of TAPSE is>17 mm. Of note, TAPSE is relatively load- and angle-dependent, and is subject to cardiac translation; however, it is the least user-dependent parameter for assessment of RV function [16].

2.2.5. Myocardial systolic excursion velocity (S’)

S’ wave is one of the most reliable and reproducible methods to assess RV systolic function, and it correlates positively with RVEF as calculated by cardiac magnetic resonance [17].The lower reference limit with pulsed DTI is set at 9.5 cm/s [7]. Of note, S’ is load-dependent and requires correction when heart rate is <70 bpm or >100 bpm; correction is achieved by multiplying S' by 75 and dividing it by the heart rate [18].

2.2.6. Fractional linear shortening and area change (FAC)

Fractional linear shortening is obtained by measuring the RVOT diameter at end-diastole and end-systole using the PSAX view. Reference limits are not set in the latest guidelines; however, “normal” values are reported with a wide range of standard variation (43% ± 18%) [19]. the main limitation in obtaining fractional linear shortening is the poor definition of the RV anterior wall. Also, there are no established landmarks for orienting the image axis at the level of the RVOT. FAC, calculated with the A4C view, is a more reliable parameter; it is defined as the difference between end-diastolic and end-systolic area divided by the end-diastolic area and multiplied by 100. Of note, FAC has been shown to correlate with RVEF as measured by magnetic resonance imaging, and lower reference value is 35% [20].

2.2.7. Right ventricular dp/dt

RV dp/dt represents rate of pressure rise in the RV and may be used to estimate RV systolic function. Compared with dp/dt in the LV, there are less data regarding the RV dp/dt, and the measurement is therefore rarely used in daily practice. RV dp/dt is obtained by measuring time required for tricuspid jet to increase in velocity from 1 to 2 m/s, and normal values are >400 mmHg/s [10]. RV dp/dt is highly load-dependent;

however, it correlates positively with TAPSE, and also it is useful for sequential assessment of RV function when loading conditions expected to be identical [21].

2.2.8. Myocardial performance index or Tei index

The RV index of myocardial performance (RIMP) reflects both systolic and diastolic RV function. Isovolumic relaxation time (IVRT), isovolumic contraction time (IVCT), and ejection time intervals are measured using either pulsed wave Doppler (PWD) or Doppler tissue imaging (DTI) at the lateral tricuspid annulus, and RIMP is equal to (IVRT + IVCT)/ejection time. Normal values are set as 0.43 by PWD and 0.54 by DTI [22].

2.2.9. Myocardial isovolumic acceleration

Myocardial acceleration during isovolumic contraction is obtained by dividing the peak isovolumic myocardial velocity by the time to peak velocity using DTI; (isovolumic acceleration) IVA is typically measured at the lateral tricuspid annulus and has the advantages of being relatively a load-independent index of global RV systolic function, with a lower reference limit set at 2.2 m/s2 [7]. IVA is not currently employed as a routine parameter for assessment of RV systolic function, but it has shown to correlate with the severity of illness in many conditions affecting the RV, including obstructive sleep apnea, mitral stenosis, and repaired tetralogy of Fallot [23].

2.2.10. Three-dimensional echocardiography

3DE allows a better anatomical definition of the RV compared to 2DE, including the base, the apex, and the outflow tract. Assessment of the RV with 3DE is feasible during routine standard echocardiography [24]. Santens et al., [25] reported that the duration of RV analysis (acquisition and off-line reconstruction) using 3DE is reasonably short, with a satisfactory quality of images. Of note, 3DE of the RV is validated as the optimal technique for assessment of RV cardiomyopathy, atrial septal defect, Ebstein's anomaly, and tetralogy of Fallot. RVEF is an integrated result of the interaction between RV contractility and load, and therefore it does not directly reflect RV contractile function per se. In view of this, 3DE allows measurement of RVEF reflecting global RV systolic performance, with a better sensitivity than 2DE. RVEF as measured by 3DE is better calculated using the volumetric semiautomated border detection method, and a value >45% reflects normal RV systolic function [9]. The main limitations to 3DE for RV assessment are poor sonographic signal and irregular rhythms. Technically, 3DE of the RV requires a different transducer (frequency of 3–4 MHz with a volumetric frame rate of 16–24 frames/s) than the one used for conventional echocardiography, and the A4C view is the most frequently used approach. Semiautomated border detection needs to be manually adjusted, and after acquisition and display of end-diastolic and end-systolic frame, long axis, planes, and volumetric data of the RV may be analyzed offline. A variety of axial cuts (cropping planes) can be obtained at the apex, mid and base of the RV, whether in the sagittal or coronal planes.

Volumetric calculation is achieved via method of disks or via mesh shell technique. Curves of regional and global RVF produced and analyzed; RV end-diastolic volume, RV end-systolic volume, and RVEF are generated [26]. Accepted normal values of RV end-diastolic volume as stated by recent guidelines are 129 ± 25 mL for men and 102 ± 33 mL for women [7]. In summary, the intrinsic ability of 3DE to directly visualize RV geometry and measure RVD and RVF without the need for geometrical assumption has resulted in significant improvement in the evaluation of the RV. This advantage was demonstrated in both accuracy and reproducibility when compared to other reference techniques, such as radionuclide ventriculography or magnetic resonance imaging [27]. Speckle tracking echocardiography for right ventricular assessment: Speckle tracking echocardiography (STE) has emerged as a new noninvasive ultrasound modality for quantifying myocardial mechanics. It evaluates tissue motion by tracking natural acoustic reflection and interference patterns within a defined ultrasound window. This tracking is performed by an image processing algorithm which tracks blocks of 20–40 pixels (Kernels), which contain markers or fingerprints also called Speckles [28]. This modality is therefore an angle independent analysis of tissue motion and deformation. Thus STE is inherently evaluates myocardial deformation or strain, as opposed to tissue Doppler strain, which indirectly computes strain from velocity gradients, Doppler derived strain is highly dependent on angle of interrogation and is therefore likely to be reliable only in apical imaging planes and unpredictable in parasternal long axis (PLAX) and short axis (SAX) planes [29].

2.2.11. Strain Analysis of the Right Ventricle

Strain echocardiography is a new imaging modality to measure myocardial deformation. It can measure intrinsic myocardial function and has been used to measure regional and global left ventricular (LV) function. Although the RV has different morphologic characteristics than the LV, strain analysis of the RV is feasible. After strain echocardiography was introduced to measure RV systolic function, it became more popular and was incorporated into recent echocardiographic guidelines. Recent studies showed that RV global longitudinal strain (RVGLS) can be used as an objective index of RV systolic function with prognostic significance [30].

2.2.12. Right ventricular longitudinal strain

Unlike other echocardiographic parameters of RV systolic function, strain values can assess intrinsic myocardial performance and can differentiate active movement from passive movement [31]. Longitudinal strain, which can be measured by Doppler tissue image (DTI) and two-dimensional speckle tracking echocarsiography (2DSTE), is a reliable and accurate way to measure RV systolic function, and has been validated in an animal study with CMR for several human cardiovascular diseases [32]. RV longitudinal strain to assess longitudinal contraction of the RV is a good marker of RV systolic function. Global longitudinal strain (GLS) by 2DSTE is the most commonly used echocardiographic parameter for detection of RV systolic function in several cardiovascular diseases. RVGLS is significantly correlated with RV ejection fraction (Pearson correlation coefficient = −0.50 to −0.80) via CMR (Lemarié et al., 2015). RVGLS significantly correlated with TAPSE (r = −0.547 to −0.83), RVFAC (r = −0.213 to −0.73), tricuspid S' velocity (r = 0.718), and RV Tei index (r = 0.590) [33]. The use of deformation imaging implies a great progress in echocardiography, as it allows assessment of segmental myocardial specific motion (ie, longitudinal, radial, and circumferential motions; twist and rotation). However, global longitudinal strain (GLS) is the most practical and useful parameter for RV assessment by STE [34]. Strain and strain rate are useful parameters for estimating RV global and regional systolic function. Longitudinal strain is calculated as the percentage of systolic shortening of the RV free wall from base to apex, while longitudinal strain rate is the rate of this shortening. RV longitudinal strain is less confounded by overall heart motion [35]. RV longitudinal strain should be measured in the RV-focused four-chamber view. Compared with STE-derived strain, the angle dependency of DTI strain is a disadvantage. RV speckle-tracking echocardiographic strain is influenced by image quality, reverberation and other artifacts, as well as attenuation. Placing the basal reference points too low (i.e., on the atrial side of the tricuspid annulus) might result in art factually low basal strain values [9].

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