Right Ventricular Mechanics Using a Novel Comprehensive Three-View Echocardiographic Strain Analysis in a Normal Population

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Background: Although quantitative right ventricular (RV) strain analysis may be useful in congenital and acquired heart disease populations with RV failure, a comprehensive, standardized approach is lacking. An 18-segment RV strain analysis obtained from three standardized RV apical echocardiographic images was used to determine the feasibility, normal values, and reproducibility of the method in normal adults.

Methods: Forty healthy, prospectively enrolled volunteers with no cardiac histories and normal QRS durations underwent echocardiography optimized for strain analysis including three RV apical views. Two-dimensional speckle-tracking longitudinal strain analysis was performed using EchoPAC software. Eleven retrospectively identified subjects with RV disease were included as a pilot population. All had been imaged using the same protocol including the three RV apical views.

Results: All control subjects had normal anatomic morphology and function by echocardiography. Feasibility of the RV strain analysis was good (adequate tracking in 696 of 720 segments [97%]). RV global peak systolic strain was $-23 \pm 2\%$. Peak strain was highest in the RV free wall and lowest in the septum. Dyssynchrony indices demonstrated no dyssynchrony using left ventricular criteria. Reproducibility of most strain measures was acceptable. This methodology identified important disease not seen in the four-chamber apical view alone in the pilot population of 11 patients with RV disease. Strain patterns and values were different from those in the control population, indicating that differences do exist from normal.

Conclusions: Eighteen-segment RV strain analysis is feasible, with strain measures falling into discrete ranges in this normal population. Those with RV disease illustrate the potential utility of this approach. These data indicate that this model can be used for more detailed studies evaluating abnormal RV populations, in which its full potential can be assessed. (J Am Soc Echocardiogr 2014;27:413-22.)

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Two-dimensional (2D) speckle-tracking echocardiography is often used for the assessment of quantitative indices of global and regional left ventricular (LV) function by means of three standardized views,[1-4] but no such multiple-view model is yet available for the right ventricle. The lack of a comprehensive right ventricular (RV) model may be due to multiple factors common in the right ventricle. These include limited target access induced by chest wall configuration in combination with the anterior retrosternal position of the right ventricle, a lack of standardized multiple RV views, and a lack of readily available RV strain analysis software.

LV strain analysis has enjoyed clinical success, in part because global and regional LV longitudinal strain is assessed in 18 segments from three standardized LV apical views.[5] RV strain analysis, on the other hand, has been performed in only a few studies using six segments from one view (apical four chamber).[6-8] To our knowledge, there are no studies using an 18-segment (18S) three-view RV strain analysis model. Early work during the development of this approach to RV strain analysis was performed in a systemic RV population (with D-transposition of the great arteries after atrial switch) at our institution and suggested the potential need for comprehensive image acquisition because of important findings seen outside of the four-chamber RV apical view (unpublished data).

Clinical RV functional assessment may be aided by a more detailed RV strain analysis that would be useful for the clinical management of patients with forms of congenital heart disease, pulmonary hypertension, RV infarction, and even LV assist devices. Furthermore, a

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Abbreviations

CRT = Cardiac resynchronization therapy

CV = Coefficient of variation

18S = 18-segment

FAC = Fractional area change

LV = Left ventricular

MOW = Maximum opposing wall delay

NYHA = New York Heart Association

RV = Right ventricular

SDttp = Standard deviation of the time-to-peak interval

6S = Six-segment

TAPSE = Tricuspid annular plane systolic excursion

2D = Two-dimensional

comprehensive 18S RV model may also be useful for the determination of regional strain abnormalities resulting from activation delays (dyssynchrony) of the right ventricle, as is found in the left ventricle.[3,9-12] This includes those with congenital heart disease and heart failure in a systemic or single right ventricle who might benefit from cardiac resynchronization therapy (CRT).[13-16]

In this study, we evaluated feasibility, reproducibility, and RV regional variability of, and propose normal ranges for, an 18S acquisition and analysis model of RV longitudinal strain for the evaluation of global and regional RV mechanics in a healthy young adult population using currently available software. Such validation in a normal population is an important precursor to the application of this comprehensive RV model to patients with heart disease. Three patients (two congenital and one with pulmonary hypertension) from a pilot group of 11 patients with abnormal right ventricles are provided to demonstrate the potential for such a model and possibilities for further investigation.

METHODS

Study Subjects

Complete transthoracic echocardiograms were obtained in 40 young, healthy, prospectively enrolled volunteer subjects, with the addition of three apical RV views optimized for strain analysis. All subjects underwent normal cardiac physical examinations. Inclusion criteria were a age ≥ 18 years at the time of the study, no history of cardiac abnormalities, normal echocardiographic findings including anatomy, LV ejection fraction ≥ 50%, fractional area change (FAC) ≥ 35%, and tricuspid annular plane systolic excursion (TAPSE) ≥ 16 mm. Exclusion criteria were any abnormal echocardiographic findings or prolonged QRS duration. Studies were obtained at Duke from March to July 2012. This study was approved by the Duke institutional review board, and all control subjects gave informed consent.

This study in the normal population was performed after noticing some regional abnormalities in patients with RV disease during routine clinical studies that prompted the development of the scanning methodology. The normal subjects were the main focus of this study.

Pilot Study Patients

An additional small pilot test population of 11 adult patients with abnormal RV function consequent to congenital or acquired disease was conducted to determine if any gross differences could be found in preliminary comparison with the normal population. These subjects were chosen from populations with RV pathology to illustrate the potential utility of the 18S model and CRT in diseased states but not to characterize abnormal populations in a comprehensive or quantitative manner. The pilot subjects were retrospectively identified for this study but had complete echocardiograms obtained with the three RV apical views.

All patients with abnormal findings had chronic elevations of RV pressure. The right ventricle was systemic in five subjects with D-transposition of the great artery (subaortic right ventricle consequent to atrial switch operations in infancy), and six had normal anatomy (subpulmonic right ventricle with acquired chronic pulmonary hypertension due to primary lung disease). All patients had New York Heart Association (NYHA) class II to IV symptoms requiring multiple heart failure medications. RV studies in the abnormal pilot group were obtained in the same fashion as in the normal population between June 2010 and July 2012.

Functional Echocardiography with Three Apical RV Views

All echocardiographic studies were acquired using a GE Vivid E9 imaging system using a 3.5-MHz ultrasound probe (GE Vingmed Ultrasound, Horten, Norway). Echocardiographic RV systolic function was assessed using the traditional markers of FAC and TAPSE measured according to the standard methodology on the four-chamber apical view in RV end-systole and end-diastole.[17] LV systolic function was assessed using the LV ejection fraction with the biplane Simpson's method.[18]

Grayscale echocardiography was performed with images optimized for longitudinal 2D speckle-tracking strain analysis (50–90 frames/sec) from three apical RV views with the subject in the standard left lateral recumbent position. The three apical RV views were equivalent to the imaging planes of the two-chamber, three-chamber, and four-chamber LV apical views but with the transducer angled rightward (Figure 1). In the early phase of this investigation, equivalent LV and RV imaging planes were ensured by starting from the LV view and simply angling rightward without changing the transducer position to obtain the RV view. However, view optimization of the "inflow" view often required repositioning of the transducer toward the left anterior axillary line, especially to image the anterior RV wall segments. Once RV landmarks were established, proper RV views were confirmed through a combination of starting with LV views and angling rightward and RV landmarks. Before performing study examinations, sonographers attended an echocardiographic strain mechanics course to learn the new RV views and to determine when an image was of adequate quality for strain analysis. The training included a more experienced observer with hand held over the examining sonographer's hand during an instructional examination to ensure proper transducer orientation at 60° rotational intervals. Sonographers performed online strain analyses at the time of study to verify the adequacy of the images.

The volumetric probe was used as an aid in development and training for 60° rotation examinations. After initial learning, this probe was no longer necessary, particularly because of its inability to supply adequate acquisition frame rates.

The views were initially termed "equivalent" in reference to preserved LV transducer plane orientations and as a reminder of where the image data should be entered into the analysis software for planar spatial reconstruction in the resulting target diagram that was designed for the left ventricle. The resulting four-chamber equivalent view has four chambers (right atrium and ventricle, left atrium and ventricle); the two-chamber equivalent view, alternatively called the "outflow" view, has three (right atrium, right ventricle, and RV outflow tract); and the three-chamber equivalent view, alternatively termed the RV "inflow" view, has two chambers (right atrium and ventricle) (Figure 1).