Right Ventricular Deformation Analyses Using a Three-Dimensional Speckle-Tracking Echocardiographic System Specialized for the Right Ventricle

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Background: Given the complex morphologic nature of the right ventricle, three-dimensional (3D) approaches would be more appropriate for assessing right ventricular (RV) function than two-dimensional approaches. Thus, the investigators have developed a novel 3D speckle-tracking echocardiographic (STE) system specialized for the right ventricle. The aim of this study was to assess the characteristics of RV global and regional deformation as well as changes on stress tests using the 3D STE system in experimental studies.

Methods: In 10 sheep, sonomicrometry crystals were implanted to validate 3D STE data in the RV endocardium of seven RV segments, including the basal and mid anterior, lateral and inferior wall, and outflow free wall. Full-volume 3D STE data sets and sonomicrometric data were acquired at baseline, during pulmonary artery banding (PAB)–induced moderate (peak RV pressure > 40 mm Hg) and severe (peak RV pressure > 60 mm Hg) RV pressure increases, and during propranolol infusion. The 3D STE area change ratio (ACR), longitudinal strain (LS), and circumferential strain (CS) were measured, and RV global and all segmental deformation data were compared between baseline and stress tests. To assess clinical feasibility, 30 control subjects and 11 patients with pulmonary arterial hypertension were enrolled.

Results: All combined 3D STE data were significantly correlated with the sonomicrometric data (ACR, R^2 = 0.88; LS, R^2 = 0.84; CS, R^2 = 0.82; P < .001). In all seven segments, the 3D STE data correlated with the sonomicrometric data (R^2 = 0.72–0.90, P < .001). Global ACR and LS data showed significant differences among baseline, moderate PAB, and severe PAB; however, CS differed only between baseline and severe PAB. The magnitudes of segmental deformation in the free wall were larger than those in the septum and apex under all conditions (P < .05) except LS during severe PAB. Segmental analyses also showed similar responses during stress tests; the ACR in each segment differed significantly between conditions. In all but the apical segments, LS showed significant reductions from moderate PAB; in contrast, CS was significantly reduced with severe PAB in all segments. In this clinical study, the acquisition rate of adequate images for analysis of the RV outflow tract was lower (75.6%) compared with the rate in other segments (from 85.4% to 100%). However, the pulmonary arterial hypertension group had lower RV global deformation values than the control group (ACR and LS, P < .001; CS, P = .003), the ACR and LS in basal and middle segments differed significantly between groups, and the outflow and apex did not differ.

Conclusions: A novel 3D STE system specialized for the right ventricle is reliable for RV deformation analyses and may provide additional information about RV global and segmental function. The clinical feasibility of this system is acceptable. (J Am Soc Echocardiogr 2016;■:■-■.)

Keywords: Three-dimensional echocardiography, Speckle-tracking echocardiography, Right ventricle, Cardiac function

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Abbreviations

ACR = Area change ratio

CS = Circumferential strain

LS = Longitudinal strain

LV = Left ventricular

M-PAB = Moderate pulmonary artery banding

PAB = Pulmonary artery banding

PAH = Pulmonary arterial hypertension

RV = Right ventricular

S-PAB = Severe pulmonary artery banding

STE = Speckle-tracking echocardiographic

3D = Three-dimensional

2D = Two-dimensional

Cardiopulmonary diseases may cause right ventricular (RV) dysfunction, and in recent years, many studies have confirmed the prognostic importance of RV function.[1-6] Echocardiography is widely used to evaluate RV function using tricuspid annular plane systolic excursion and RV fractional area change.[7,8] However, assessing RV function using conventional echocardiography is difficult because of the complex nature of the RV structure and contraction in contrast to the ellipsoidal left ventricle.[9] As with the left ventricle, RV deformation imaging would provide additional information about RV pathophysiology. Two-dimensional (2D) speckle-tracking echocardiographic (STE) systems have been used to quantitate RV myocardial deformation, which could be assessed by longitudinal strain (LS) but not circumferential strain (CS), because of the complex nature of the RV structure in contrast to the ellipsoidal left ventricle.[9-11] Thus, RV global and regional deformation has not been well studied noninvasively, because an appropriate system has not yet been developed.

Given the complex nature of the right ventricle, a three-dimensional (3D) approach would be more appropriate than a 2D approach. We developed a 3D STE system for the left ventricle, and the pathophysiology and clinical feasibility of various strain components as possible imaging biomarkers were subsequently studied.[12,13] To overcome the limitation of 2D speckle-tracking echocardiography for assessing RV function, we recently reported on the preliminary use of a 3D STE system designed for left ventricular (LV) analysis and showed that 3D speckle-tracking echocardiography is useful for evaluating RV function with deformation data.[14] Similarly, Smith *et al.*[15] reported that 3D STE deformation data were associated with clinical outcomes in patients with pulmonary hypertension using the same system. However, the current 3D STE system, which is specialized for the left ventricle, may be inadequate for accurately demonstrating RV structure and function.[14,15] Thus, we developed a new 3D STE system that features a specialized algorithm for the right ventricle and sought to assess the characteristics of RV global and regional deformation with the system in experimental studies and to confirm the clinical feasibility of evaluating global and regional deformation data in normal subjects and in a small group of patients with pulmonary arterial hypertension (PAH).

METHODS

Animal Preparation

In this study, we used 10 male hybrid Suffolk sheep (Japan Lamb, Ltd, Hiroshima, Japan) weighing, on average, 27.5 kg. The study was approved by the Institutional Animal Experiment Committee of the University of Tsukuba and conducted in compliance with our university's regulations for animal experiments and the "Fundamental Guideline for Proper Conduct of Animal Experiment and Related Activities in Academic Research Institutions" of the Ministry of Education, Culture, Sports, Science and Technology.

General anesthesia was induced with thiamylal sodium (10-15 mg/kg intravenously), and endotracheal intubation was performed. Anesthesia was maintained with isoflurane (1.5%-2%) and oxygen. Two 5-F micromanometer-tipped catheters (Millar Instruments, Houston, TX) were inserted into the right ventricle via the jugular vein and into the left ventricle via the femoral artery to measure the ventricular pressure and maximal rate increase in LV pressure (dP/dt max) for each condition. Pressure data were digitized and stored on a personal computer for analysis with dedicated software. A median sternotomy was performed, and an incision was made in the pericardium avoiding the apical area.

Sonomicrometry

We implanted sonomicrometry crystals (2-mm diameter; Sonometrics Corporation, London, ON, Canada) at the RV endocardium in seven segments, including the basal and mid anterior, lateral and inferior wall, and outflow free wall. (For detailed methods, see Supplemental Figure 1.) Sonomicrometry crystals were implanted in four or five of the seven segments in each sheep, because they could not be implanted simultaneously in all segments.

Sonomicrometric data were acquired immediately after the corresponding echocardiographic images were recorded, and the data were analyzed using CardioSOFT Pro (Sonometrics Corporation). Strain was calculated as $[L(t) - L_0]/L_0$, where $L(t)$ is segment length at time t, and L_0 is segment length at the onset of the QRS complex. The LS of the basal segment was measured between the basal and mid endocardial crystals, whereas the LS of the mid segment was measured between the mid and apical endocardial crystals. The CS of the basal and mid segments was measured between each endocardial crystal pair. The area change ratio (ACR) was calculated using a function in CardioSOFT that can multiply two sonomicrometric curves. The ACR was calculated with a longitudinal and circumferential curve of each segment.[12,13] All strain data were calculated by averaging data from 10 consecutive heartbeats. Any curves that were not recorded clearly were excluded from the analysis.

Echocardiography

Echocardiographic examinations were performed with an ARTIDA ultrasonography system (Toshiba Medical Systems, Tochigi, Japan). Full-volume electrocardiography-gated 3D data sets with six sectors were acquired in the apical position using a matrix-array 2.5-MHz transducer. In each study, the heart was repositioned within the apical pericardium to control for apical motion. A peritoneal incision was made to acquire the appropriate 3D apical images through the diaphragm. The animal's breathing was stopped during the image acquisition process. The volume rate of each image was set at 30 to 40 Hz. The data were stored and transferred to a computer (Inspiron 1300; Dell, Inc, Round Rock, TX) for offline analysis. The images were analyzed with prototype software for the right ventricle.

We used a 3-MHz transducer for conventional echocardiography. LV volume and ejection fraction were measured using the modified Simpson's rule.[16] RV diameter and function were determined with RV diameter (length, papillary muscle, and basal level), fractional area change, tricuspid annular plane systolic excursion, and peak systolic velocity of the tricuspid annulus using the tissue Doppler method.