Dynamic Assessment of Right Ventricular Volumes and Function by Real-Time Three-Dimensional Echocardiography: A Comparison Study With Magnetic Resonance Imaging in 100 Adult Patients

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Background: The aim of this study was to validate a novel real-time three-dimensional echocardiographic (RT3DE) analysis tool for the determination of right ventricular volumes and function in unselected adult patients.

Methods: A total of 100 consecutive adult patients with normal or pathologic right ventricles were enrolled in the study. A dynamic polyhedron model of the right ventricle was generated using dedicated RT3DE software. Volumes and ejection fractions were determined and compared with results obtained on magnetic resonance imaging (MRI) in 88 patients with adequate acquisitions.

Results: End-diastolic, end-systolic, and stroke volumes were slightly lower on RT3DE imaging than on MRI (124.0 ± 34.4 vs 134.2 ± 39.2 mL, $P < .001$; 65.2 ± 23.5 vs 69.7 ± 25.5 mL, $P = .02$; and 58.8 ± 18.4 vs 64.5 ± 24.1 mL, $P < .01$, respectively), while no significant difference was observed for ejection fraction (47.8 ± 8.5% vs 48.2 ± 10.8%, $P = .57$). Correlation coefficients on Bland-Altman analysis were $r = 0.84$ (mean difference, 10.2 mL; 95% confidence interval [CI], −31.3 to 51.7 mL) for end-diastolic volume, $r = 0.83$ (mean difference, 4.5 mL; 95% CI, −23.8 to 32.9 mL) for end-systolic volume, $r = 0.77$ (mean difference, 5.7 mL; 95% CI, −24.6 to 36.0 mL) for stroke volume, and $r = 0.72$ (mean difference, 0.4%; 95% CI, −14.2% to 15.1%) for ejection fraction.

Conclusion: Right ventricular volumes and ejection fractions as assessed using RT3DE imaging compare well with MRI measurements. RT3DE imaging may become a time-saving and cost-saving alternative to MRI for the quantitative assessment of right ventricular size and function. (J Am Soc Echocardiogr 2010;23:116-26.)

Keywords: Three-dimensional echocardiography, Magnetic resonance imaging, Cardiac volume, Right ventricle, Imaging

Experimental studies on open-chest canine models in the 1940s and 1950s suggested that even extensive damage to the right ventricular (RV) wall does not significantly influence circulation.[1] In fact, the right ventricle is not a mere bystander but plays an important role in cardiac hemodynamics. In the 1980s and 1990s, it was demonstrated that RV dysfunction is an independent prognostic factor in a variety of diseases.[2] However, because of the complex shape of the right ventricle, the reliable quantitative assessment of its size and function has remained an unresolved issue. Conventional echocardiographic methods do not enable RV volume measurements and provide only surrogates of ejection fraction.[3] Hence, methods that allow the chamber to be portrayed in three dimensions appear likely to be the future techniques of choice.[4] Various three-dimensional (3D) echocardiographic techniques have been applied for the evaluation of the right ventricle.[5] With the advent of real-time 3D echocardiographic (RT3DE) imaging, a technique is available that enables the rapid acquisition of 3D data sets. Initial studies using RT3DE imaging were based on the provisional use of software dedicated to the left ventricle.[6] Recently, an analysis tool especially designed for the reconstruction of a dynamic polyhedron RV model has been developed. Two initial validation studies in groups of predominantly pediatric patients yielded good agreement with magnetic resonance imaging (MRI).[7,8] The aim of the present study was to assess for the first time the accuracy and reproducibility of the novel technique in a large cohort of unselected adult patients.

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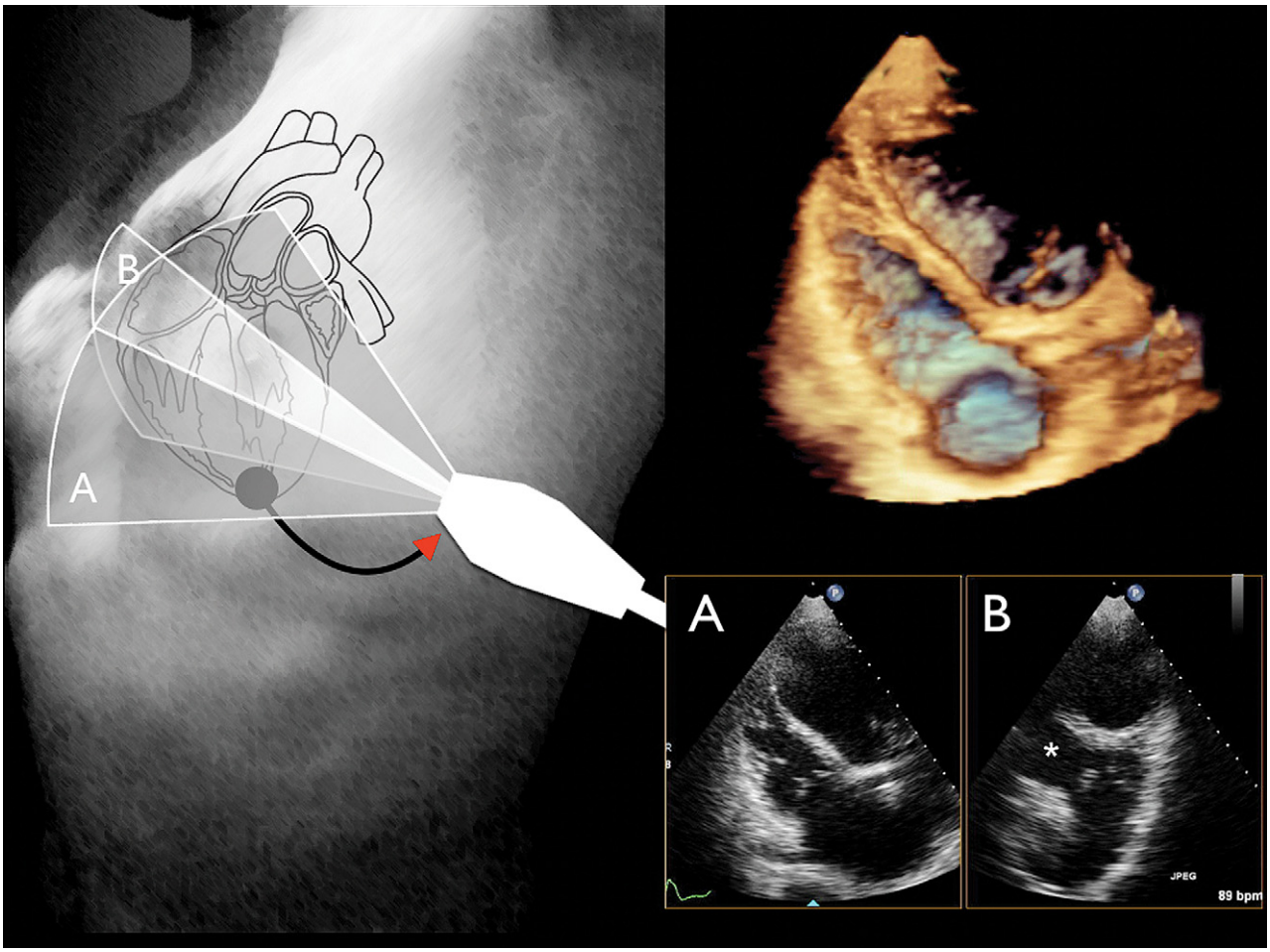

Figure 1 RT3DE imaging of the right ventricle. *(Left)* For full coverage of the right ventricle by the 3D pyramidal data volume, the observer should use a modified apical view: compared with the standard apical view *(black dot)*, the transducer must be positioned more laterally. This is of critical importance to cover the upper anterior wall and the outflow tract. *(Top right)* Color-coded 3D image of the right ventricle. *(Bottom right)* **(A)** Modified 4-chamber view of the right ventricle. **(B)** Corresponding 90° rotated image with good visualization of the outflow tract *(asterisk)*.

METHODS

Study Population

One hundred adult patients who underwent clinically indicated cardiac MRI were included prospectively from October 2007 to December 2008. The patients were included solely on the basis of indications for MRI, so the study population was unbiased regarding echocardiographic image quality. In 97% of the patients, RT3DE imaging and MRI were performed on the same day to minimize the impact of changing loading conditions. In the remaining 3 patients, RT3DE acquisitions were performed <24 hours after MRI. Informed consent was obtained from all patients. The study protocol was approved by the local institutional review committee.

RT3DE Imaging

RT3DE Data Set Acquisition. All 3D data sets were acquired using a Philips iE33 ultrasound system equipped with a matrix-array X3-1 transducer (Philips Medical Systems, Andover, MA). Acquisitions were performed using a modified apical view to enable full coverage of the entire right ventricle by the pyramidal volume, with particular attention to the upper anterior wall and RV outflow tract (Figure 1, Video 1; view video clip online). The optimal position of the probe was controlled by stepwise 360° rotation of the modified apical view. Sector size and depth were chosen carefully to achieve the highest possible frame rate. Then a data set was recorded over 7 cardiac cycles. An average of 4 to 6 data sets were acquired per patient, and the data set with the highest image quality was used for further analysis.

RT3DE Data Analysis. Three-dimensional data sets were analyzed offline using the novel dedicated software (4D RV-Function CAP 1.1; TomTec Imaging Systems, Inc, Unterschleissheim, Germany) and a software platform for data management (Research Arena 2.0; TomTec Imaging Systems, Inc). In brief, the work flow of the RV analysis software is as follows: Step 1, view adjustment: within the 3D data set, 3 orthogonal main cut planes are selected (Figure 2, Video 2; view video clip online), and the observer can define the end-diastolic and end-systolic frames within the sequence as well as several landmarks. Step 2, setting of initial contours: on the basis of the initial view adjustment and the landmarks, the program automatically provides 4-chamber, sagittal, and coronal views of the right ventricle. The observer draws

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