Echocardiographic Linear Dimensions for Assessment of Right Ventricular Chamber Volume as Demonstrated by Cardiac Magnetic Resonance

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Background: Echocardiography-derived linear dimensions offer straightforward indices of right ventricular (RV) structure but have not been systematically compared with RV volumes on cardiac magnetic resonance (CMR).

Methods: Echocardiography and CMR were interpreted among patients with coronary artery disease imaged via prospective (90%) and retrospective (10%) registries. For echocardiography, American Society of Echocardiography–recommended RV dimensions were measured in apical four-chamber (basal RV width, mid RV width, and RV length), parasternal long-axis (proximal RV outflow tract [RVOT]), and short-axis (distal RVOT) views. For CMR, RV end-diastolic volume and RV end-systolic volume were quantified using border planimetry.

Results: Two hundred seventy-two patients underwent echocardiography and CMR within a narrow interval (0.4 ± 1.0 days); complete acquisition of all American Society of Echocardiography–recommended dimensions was feasible in 98%. All echocardiographic dimensions differed between patients with and those without RV dilation on CMR ($P < .05$). Basal RV width ($r = 0.70$), proximal RVOT width ($r = 0.68$), and RV length ($r = 0.61$) yielded the highest correlations with RV end-diastolic volume on CMR; end-systolic dimensions yielded similar correlations ($r = 0.68$, $r = 0.66$, and $r = 0.65$, respectively). In multivariate regression, basal RV width (regression coefficient = 1.96 per mm; 95% CI, 1.22-2.70; $P < .001$), RV length (regression coefficient = 0.97; 95% CI, 0.56-1.37; $P < .001$), and proximal RVOT width (regression coefficient = 2.62; 95% CI, 1.79-3.44; $P < .001$) were independently associated with CMR RV end-diastolic volume ($r = 0.80$). RV end-systolic volume was similarly associated with echocardiographic dimensions (basal RV width: 1.59 per mm [95% CI, 1.06-2.13], $P < .001$; RV length: 1.00 [95% CI, 0.66-1.34], $P < .001$; proximal RVOT width: 1.80 [95% CI, 1.22-2.39], $P < .001$) ($r = 0.79$).

Conclusions: RV linear dimensions provide readily obtainable markers of RV chamber size. Proximal RVOT and basal width are independently associated with CMR volumes, supporting the use of multiple linear dimensions when assessing RV size on echocardiography. (J Am Soc Echocardiogr 2016;■:■-■.)

Keywords: Right ventricle, Echocardiography, Cardiovascular magnetic resonance

Abnormal right ventricular (RV) chamber geometry is an established prognostic marker for a broad array of cardiovascular conditions, including coronary artery disease (CAD).[1,2] Echocardiography-derived linear dimensions are widely used to assess left ventricular (LV) geometry, for which their use has been validated by anatomic correlation and prediction of prognosis.[3-6] However, the utility of echocardiography for RV assessment is less certain.[7,8] Despite known limitations posed by RV geometric complexity, American Society of Echocardiography (ASE) guidelines encompass multiple linear measurements for the assessment of RV chamber size, including measurements acquired in apical four-chamber, parasternal long-axis, and parasternal short-axis views.[3] The relative utility of different echocardiographic linear measurements for assessment of RV size is not known.

Cardiac magnetic resonance (CMR) provides excellent endocardial definition that allows RV chamber size to be quantified without geometric assumptions. Prior studies have shown close agreement between CMR results and ex vivo phantom volumes[9] and demonstrated CMR measurements of RV structure and function to be reproducible.[10,11] Echocardiographic RV linear measurements have been compared with those obtained on CMR in prior cohorts.[8,12,13] However, insights regarding the utility of echocardiographic linear dimensions have been limited by methodologic issues that have included the acquisition of select echocardiographic measurements (preventing comparison of

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This study was funded by NIH 1R01HL128278-01 (J.W.W.) and K23 HL102249-01 (J.W.W.).

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0894-7317/$36.00

http://dx.doi.org/10.1016/j.echo.2016.05.002

Abbreviations

ASE = American Society of Echocardiography

BSA = Body surface area

CAD = Coronary artery disease

CMR = Cardiac magnetic resonance

ESV = End-systolic volume

EDV = End-diastolic volume

LV = Left ventricular

PCI = percutaneous coronary intervention

RV = Right ventricular

RVEF = Right ventricular ejection fraction

RVOT = Right ventricle outflow tract

3D = Three-dimensional

individual measurements with one another), small sample size (limiting the generalizability of previously reported weak correlations), and prolonged intervals between echocardiography and CMR (an important concern in the context of the known sensitivity of the right ventricle to loading conditions).

In this study we examined RV structure and function among a broad cohort of patients with CAD undergoing echocardiography and CMR within a narrow interval. In all patients, a uniform echocardiographic protocol was performed, which included assessment of RV chamber geometry in standard orientations concordant with consensus guidelines.[3] The aims were twofold: (1) to determine the feasibility and reproducibility of guideline-recommended RV linear measurements in a diverse CAD cohort and (2) to compare the magnitude of association between different echocardiography-based dimensions and CMR-quantified RV chamber volumes.

METHODS

Population

The population comprised patients with CAD accrued from separate research registries at Weill Cornell Medical College, each of which was focused on multimodality imaging for the assessment of ischemic heart disease. Among these patients, 90% ($n = 246$) were accrued prospectively as part of National Institutes of Health protocols using CMR and echocardiography for CAD-associated remodeling (1R01HL128278-01 and K23 HL102249-01),[14] and 10% were accrued through a retrospective registry of patients with chronic obstructive CAD as verified by invasive angiography.[15]

For all patients, CMR and echocardiography were performed within 7 days, without interval coronary revascularization between imaging tests. Patients with contraindications to CMR (e.g., glomerular filtration rate < 30 mL/min/1.73 m^2, ferromagnetic implants) were excluded from participation. Comprehensive demographic data were collected, including cardiac risk factors, medications, and invasive angiography–assigned infarct-related artery. This study was conducted with approval from the Weill Cornell Medical College Institutional Review Board.

Imaging Protocol

Echocardiography and CMR were each performed using a standardized image acquisition protocol:

Echocardiography. Transthoracic echocardiography was performed using commercial equipment (Vivid 7 [GE Healthcare, Little Chalfont, United Kingdom], SC2000 [Siemens Healthcare, Malvern, PA]). Echocardiography included evaluation of the right ventricle from the parasternal long- and short-axis and RV-focused apical four-chamber views, as specified in consensus ASE guidelines.[3]

CMR. CMR was performed using 1.5- and 3.0-T scanners (GE Medical Systems, Waukesha, WI). Cine CMR involved a steady-state free precession pulse sequence. Images were acquired in standard LV short- and long-axis planes. Short-axis images were acquired throughout the right ventricle such that images extended from the pulmonic valve through the RV apex.

RV Chamber Quantification

Echocardiography and CMR were interpreted by experienced physicians (J.K. and J.W.W., respectively) using a prespecified analytic approach for each modality.

Echocardiography. RV linear dimensions were made in orientations concordant with ASE guidelines[7]:

- In the apical four-chamber view, RV width was measured in two locations: (1) basal RV width (maximal transverse diameter in the basal third of the right ventricle) and (2) mid RV width (maximal transverse diameter in the middle third of the right ventricle, approximately at the level of the papillary muscles). In addition, RV length was measured as the maximal distance from the tricuspid annulus to the apex.
- In the parasternal long-axis view, proximal RV outflow tract (RVOT) width was measured as the maximal distance (perpendicularly oriented) between the RV free wall and the septal-aortic junction.
- In the parasternal short-axis (pulmonary bifurcation) view, distal RVOT width was measured as the maximal distance immediately proximal to the pulmonic valve. When pulmonary bifurcation–focused view was not available, a nonfocused view of the pulmonic valve in the short axis was used for approximation of the pulmonic valve annulus.

Figure 1 provides representative examples of each RV dimension; all were measured during both end-diastole and end-systole. For the purpose of standardization, measurements in each respective orientation were acquired using the image and cardiac cycle that provided the largest linear dimension.

RV systolic function was assessed via tricuspid annular plane systolic excursion, S′ and fractional area change, which were acquired in accordance with consensus guidelines.[3]

CMR. Volumetric quantification was performed using short-axis cine CMR images. Basal and apical image positions were defined in accordance with standard criteria, with the basal right ventricle defined by the image in which the pulmonic valve or valve annulus was visualized and the apex defined by the distal-most image in which the RV myocardium was visualized. End-diastole and end-systole were defined on the basis of the respective frames demonstrating the largest and smallest cavity sizes. Quantification of end-diastolic volume (EDV) and end-systolic volume (ESV) was performed using short-axis images inclusive of trabeculations and papillary muscle. RV ejection fraction (RVEF) was calculated based on EDV and ESV. Cine CMR analysis was performed using a previously validated automated algorithm shown to have excellent agreement with both manual planimetry–quantified cardiac chamber size and phantom-verified volumes.[9,16,17]

Reproducibility

Intra- and interreader reproducibility was tested in a random cohort comprising 10% ($n = 26$) of the study population, among whom