Three-Dimensional Echocardiography for the Assessment of Right Ventriculo-Arterial Coupling

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Background: The analysis of right ventriculo-arterial coupling (RVAC) from pressure-volume loops is not routinely performed. RVAC may be approached by the combination of right heart catheterization (RHC) pressure data and cardiac magnetic resonance (CMR)–derived right ventricular (RV) volumetric data. RV pressure and volume measurements by Doppler and three-dimensional echocardiography (3DE) allows another way to approach RVAC.

Methods: Ninety patients suspected of having pulmonary hypertension underwent RHC, 3DE, and CMR (RHC mean pulmonary artery pressure [mPAP] 37.9 ± 11.3 mm Hg; range, 15–66 mm Hg). Three-dimensional (3D) echocardiography was performed in 30 normal patients (echocardiographic mPAP 18.4 ± 3.1 mm Hg). Pulmonary artery (PA) effective elastance (Ea), RV maximal end-systolic elastance (Emax), and RVAC (PA Ea/RV Emax) were calculated from RHC combined with CMR and from 3DE using simplified formulas including mPAP, stroke volume, and end-systolic volume.

Results: Three-dimensional echocardiographic and RHC-CMR measures for PA Ea (3DE, 1.27 ± 0.94; RHC-CMR, 0.71 ± 0.52; r = 0.806, P < .001), RV Emax (3DE, 0.72 ± 0.37; RHC-CMR, 0.38 ± 0.19; r = 0.798, P < .001), and RVAC (3DE, 2.01 ± 1.28; RHC-CMR, 2.32 ± 1.77; r = 0.826, P < .001) were well correlated despite a systematic overestimation of 3DE elastance parameters. Among the whole population, 3D echocardiographic PA Ea and 3D echocardiographic RVAC but not 3D echocardiographic RV Emax were significantly lower in patients with mPAP < 25 mm Hg (n = 41) than in others (n = 79). Among the 90 patients who underwent RHC, 3D echocardiographic PA Ea and 3D echocardiographic RVAC but not 3D echocardiographic RV Emax increased significantly with increasing levels of pulmonary vascular resistance.

Conclusions: Three-dimensional echocardiography–derived PA Ea, RV Emax, and RVAC correlated well with the reference RHC-CMR measurements. Ea and RVAC but not Emax were significantly different between patients with different levels of afterload, suggesting failure of the right ventricle to maintain coupling in severe pulmonary hypertension. (J Am Soc Echocardiogr 2018;■:■-■.)

Keywords: Right ventricle, Right ventricular coupling, Right ventricular function, Three-dimensional echocardiography, Pulmonary circulation

The response of the right ventricle to various cardiac and pulmonary diseases has been shown to influence outcomes. This is of particular importance in pulmonary arterial hypertension, in which the mechanisms of right heart failure have been documented.[1] Significant advances in echocardiography, cardiothoracic computed tomography, and cardiac magnetic resonance (CMR) in the past decade have enabled a noninvasive approach to assessment of the right heart–pulmonary circulation unit,[2] which was classically best analyzed using invasive hemodynamics.[3] Right ventricular (RV) volumes and ejection fraction only provide a limited aspect of the right heart–pulmonary circulation unit, as not only RV intrinsic performance but also preload and mostly afterload influence the global RV response to various hemodynamic states. Afterload of the right ventricle is often considered only as pulmonary artery (PA) pressure and pulmonary vascular resistance (PVR), which both can be easily obtained by right heart catheterization (RHC) and estimated by echocardiography. However, PVR represents only the steady component of RV afterload and does not take into account the hydraulic or pulsatile component, represented mostly by arterial elastance (or compliance) and wave reflection.[4,5]

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Conflicts of Interest: None.

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Abbreviations

3D = Three-dimensional

3DE = Three-dimensional echocardiography

CMR = Cardiac magnetic resonance

Ea = Effective arterial elastance

Emax = Maximal end-systolic elastance

ESP = End-systolic pressure

ESV = End-systolic volume

mPAP = Mean pulmonary artery pressure

PA = Pulmonary artery

PH = Pulmonary hypertension

PVR = Pulmonary vascular resistance

RHC = Right heart catheterization

RV = Right ventricular

RVAC = Right ventriculo-arterial coupling

RVEF = Right ventricular ejection fraction

sPAP = Systolic pulmonary artery pressure

SV = Stroke volume

In the early stages of pulmonary hypertension (PH), RV intrinsic contractile function and load are adequately coupled; however, with further chronic increase of afterload, the right ventricle becomes unable to proportionally enhance its contractility, leading to progressive right heart failure.[6] Pressure-volume relations provide essential information about right ventriculo-arterial coupling (RVAC). Despite their clinical value, especially in the field of PH, measurements of effective arterial elastance (Ea), maximal end-systolic elastance (Emax), and RVAC from pressure-volume loops are not routinely performed, because of technical complexity. An alternative method has been derived from the combination of RHC pressure data and CMR-derived RV volumetric data.[7] Echocardiography, which allows simultaneous pressure estimation from Doppler velocities and volume measurement using the three-dimensional (3D) technique, could be another way to estimate RVAC.

We aimed (1) to compare estimations of PA Ea, RV Emax, and RVAC obtained from Doppler analysis and real-time 3D echocardiographic acquisitions with those obtained using the combination of RHC and CMR, (2) to calculate these parameters using echocardiography in a population of normal patients in order to obtain reference values, and (3) to compare these echocardiography-derived parameters according to the level of afterload as estimated either by mean pulmonary artery pressure (mPAP) or by calculation of PVR during RHC.

METHODS

Study Population

Our population was retrospectively selected among patients referred to the University Hospital of Nancy (Vandoeuvre-les-Nancy, France) for the evaluation of known or suspected PH. A total of 1,283 RHCs were performed in 537 patients between January 2010 and December 2016. Only stable patients who underwent RHC, CMR, and 3D echocardiography (3DE) were included. CMR was performed during the same evaluation as RHC in 432 cases. Although complete standard echocardiography was performed in all patients every time they underwent RHC, 3D images centered on the right ventricle were not systematically acquired in all patients. Finally, we retrospectively identified 134 patients who underwent RHC, CMR, and 3DE for their usual clinical management. Those three examinations were performed within 12 days of one another in 90 patients, constituting the final study population. Complete echocardiographic examinations, including 3D acquisitions of the right ventricle, were also performed in 30 normal patients selected from our echocardiographic database if they had 3D acquisitions centered on the right ventricle.

This retrospective study complied with the Declaration of Helsinki. Although French law does not require ethics committee approval or informed consent for retrospective data collection, the data were anonymized and complied according to the requirements of Commission Nationale Informatique et Liberté, the organization dedicated to privacy, information technology, and civil rights in France.

Two-Dimensional Echocardiography

Two-dimensional echocardiographic examinations were performed using V9 and V95 systems with the M5S probe (GE Vingmed Ultrasound, Horten, Norway), and the following measurements were obtained using EchoPAC version 2.0.1. RV fractional area change was defined as the percentage change between the RV chamber area in end-diastole and end-systole by planimetry in the apical four-chamber view. Tricuspid annular plane systolic excursion was defined as the difference between the displacement of the RV lateral annulus from end-diastole to end-systole obtained by M-mode imaging in the apical four-chamber view centered on the right ventricle. Peak systolic velocity (S′) of the tricuspid annulus was obtained using pulsed-wave Doppler at the tricuspid level of the RV free wall.[8,9] For two-dimensional speckle-tracking strain echocardiography, manual trace of the RV free wall endocardial border was drawn, then the software automatically tracked it throughout the cardiac cycle, and strain values were automatically obtained. Estimation of systolic pulmonary artery pressure (sPAP) was made as usual from the continuous-wave Doppler spectrum of the tricuspid regurgitation. Right atrial pressure was estimated using the formula right atrial pressure $= 1.7 \times (Et/e't) + 0.8$, where Et corresponds to the maximal early diastolic velocity through the tricuspid valve and e′t corresponds to the maximal velocity of the lateral tricuspid annulus in diastole.[10] Echocardiographic mPAP was approximated from sPAP using Chemla's formula: echocardiographic mPAP $= 0.61 \times$ sPAP + 2 mm Hg,[11] as this formula had a good correlation and acceptable limits of agreement compared with RHC mPAP (Supplemental Table 1, available at www.onlinejase.com).

Three-Dimensional Echocardiographic Imaging Acquisitions

Three-dimensional echocardiographic acquisitions were obtained after the two-dimensional examination by the same experienced sonographer (C.S.-S., O.H., C.V.) using the 4V probe. Acquisitions were obtained from the four-chamber apical view adapted to improve visualization of the right ventricle. For each patient, a full volume was obtained from six consecutive cardiac cycles during a single breath-hold to avoid translational motion. Echocardiographic data sets were stored digitally for post hoc analysis.

Postprocessing for Quantification of RV Volumes and Function

Postprocessing analysis and 3D reconstruction were all performed offline by the same observer (R.A.) unaware of the results of RHC and CMR using TomTec software (4D RV-Function 2.0, TomTec-Arena; TomTec Imaging Systems, Unterschleissheim, Germany). The following landmarks were manually defined: (1) left ventricular and