2D Echocardiographic Evaluation of Right Ventricular Function Correlates With 3D Volumetric Models in Cardiac Surgery Patients

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Objectives: The early diagnosis and treatment of right ventricular (RV) dysfunction are of critical importance in cardiac surgery patients and impact clinical outcome. Two-dimensional (2D) transesophageal echocardiography (TEE) can be used to evaluate RV function using surrogate parameters due to complex RV geometry. The aim of this study was to evaluate whether the commonly used visual evaluation of RV function and size using 2D TEE correlated with the calculated three-dimensional (3D) volumetric models of RV function.

Design and Setting: Retrospective study, single center, University Hospital.

Participants and Intervention: Seventy complete datasets were studied consisting of 2D 4-chamber view loops (2-3 beats) and the corresponding 4-chamber view 3D full-volume loop of the right ventricle. RV function and RV size of the 2D loops then were assessed retrospectively purely qualitatively individually by 4 clinician echocardiographers certified in perioperative TEE. Corresponding 3D volumetric models calculating RV ejection fraction and RV end-diastolic volumes then were established and compared with the 2D assessments.

Measurements and Main Results: 2D assessment of RV function correlated with 3D volumetric calculations (Spearman's rho –0.5; $p < 0.0001$). No correlation could be established between 2D estimates of RV size and actual 3D volumetric end-diastolic volumes (Spearman's rho 0.15; $p = 0.25$).

Conclusion: The 2D assessment of right ventricular function based on visual estimation as frequently used in clinical practice appeared to be a reliable method of RV functional evaluation. However, 2D assessment of RV size seemed unreliable and should be used with caution.

KEY WORDS: 2-dimensional TEE, 3-dimensional TEE, right ventricle, ejection fraction

Assessment of right ventricular (RV) function is of substantial clinical importance in cardiac surgery and has an impact on patient outcome and prognosis.[1–4] Echocardiography is the most commonly used imaging technique to assess RV function in clinical practice.[2] Transesophageal echocardiography (TEE) is performed routinely perioperatively in cardiac surgery patients. Due to its complex geometry, an accurate evaluation of the right ventricular ejection fraction (RVEF) using surrogate parameters such as tricuspid annular plane systolic excursion and tissue Doppler-derived lateral tricuspid annular velocities are not always reliable, whereas other parameters such as RV fractional area change (RVFAC) correlate with the actual cardiac magnetic resonance (CMR)-derived RVEF.[2,3] However, quick decisions sometimes have to be made under extreme time pressure in order to initiate the correct treatment when time for complex area tracings and volumetric calculations is sparse. In acute clinical situations in which time management can be an issue, the visual two-dimensional (2D) echocardiographic evaluation assessing RV function, derived from the Focus Assessed Transthoracic Echo (FATE) protocol, still plays an important role in clinical practice.[4]

Three-dimensional (3D) echocardiography increasingly has become a standard in cardiology, operating rooms, and critical care units worldwide.[5] Unfortunately, 3D assessment of RV function and RV filling using calculated 3D volume models remains time consuming and has not been incorporated in routine clinical decision-making protocols to date. Imaging technologies such as CMR have become the *gold standard* for the assessment of right ventricular function.[6] Multiple studies successfully have validated 3D echocardiography and the resulting 3D volume models towards CMR.[7–11]

However, neither CMR nor 3D volumetric analysis of the RV by echocardiography is readily available as bedside tools when dealing with an acute clinical situation, especially in the perioperative setting.

The goal of the present study was to evaluate whether the visual real-time assessment of RV function in 2D TEE correlated with the calculated RV ejection fraction and end-diastolic volumes derived from a 3D volumetric model.

PATIENTS AND METHODS

Patients

Approval for this retrospective study was obtained from the Institutional Review Board of the University Hospital Tübingen, Germany. Patient records were anonymous and de-identified prior to data analysis.

A retrospective analysis in the institutional echo database was performed. Ninety-one datasets consisting of a 2D and 3D loop in midesophageal 4-chamber view from 70 adult patients undergoing cardiac surgery between April and December 2014 at the University Hospital Tübingen, Germany were analyzed (Table 1).

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TEE

As per institutional standard, each patient undergoing cardiac surgery in the absence of contraindications receives a comprehensive 2D TEE examination following current guidelines.[8]

In addition, a 3D study consisting of full-volume loops of the right and left ventricle after the induction of anesthesia and before the initiation of cardiopulmonary bypass under stable hemodynamic conditions was performed. 2D and 3D echocardiograms were recorded at similar time points in order to be able to compare data and to eliminate changing hemodynamic conditions as confounders.

Of the identified 91 datasets, 3 had to be excluded due to stitching artifacts in the 3D loop, and 18 had to be excluded due to a low frame rate in the 3D loop.

Finally, 70 complete datasets were analyzed and consisted of one 2D 4-chamber view loop (2 beats) and the corresponding 4-chamber view 3D full-volume loop of the right ventricle (multibeat acquisition with 4 beats) (Philips S7-2t Omni or Philips X7-2t Matrix, Philips Healthcare, Inc., Andover, MA). 2D loops of the 4-chamber view were anonymized and exported as audio-video interleave files in the original image size and speed (Philips DICOM Viewer R3.0-SP03, Philips, Netherlands) (Fig 1). The files then were presented individually to 4 different cardiac anesthesiologists all certified to perform perioperative TEE, all of whom had 10+ years of clinical experience in cardiac anesthesia. No information regarding the performed surgical case, hemodynamic status, or the patient's medical history was revealed to the examiners. Each clinician had to fill out a form commenting on the size and function of the right ventricle exclusively based on one 2D loop 4-chamber view per patient. All 2D assessments of RV function were purely qualitative, and all examiners were blinded to the results of the other examiners. For estimating the RV size, the clinicians could choose among 3 options—*small*, *normal*, and *large*. For estimating the RV function, the options to choose were *normal*, *mildly reduced*, and *severely reduced*.

Table 1. Demographic Patient Data and Performed Surgical Procedures

Patients	n = 70
Sex	Female (n = 22)
	Male (n = 48)
Age	14-87 years (median = 66.5 years)
BSA	1.39-2.43 m² (median = 1.93m²)
Surgical procedures	Off-pump myocardial revascularization (n = 7)
	On-pump myocardial revascularization (n = 17)
	Aortic valve surgery (n = 5)
	Mitral valve surgery (n = 10)
	Thoracic aortic aneurysm repair (n = 2)
	LVAD implantation (n = 9)
	ECLS, Impella® implantation or weaning (n = 4)
	Combination surgery (eg, aortic valve and ascending aortic aneurysm repair, aortic and mitral valve repair) (n = 10)
	Acute Stanford type-A dissection repair (n = 3)
	Other (pulmonary valve replacement, pulmonary artery conduit, right atrial tumor resection) (n = 3)

Abbreviations: BSA, body surface area; ECLS, extracorporeal life support; LVAD, left ventricular assist device.

The corresponding 3D full-volume loops (4 beats) of the right ventricle then were analyzed separately by 2 different cardiac anesthesiologists certified in perioperative TEE and trained in using Tomtec 4D RV Function® Software (Ver. 2.0, TomTec Imaging System GmbH, Unterschleissheim, Germany). The group of clinicians evaluating the 2D loops were blinded completely to the 3D loops and the clinicians from the 3D group had not seen the corresponding 2D echo loops. Using the Tomtec 4D RV Function® Software, a four-dimensional model of the right ventricle then was established (Fig 1). End-systolic (ESV) and end-diastolic (EDV) volumes of the RV, indices of ESV (ESVI) and EDV (EDVI), as well as the RVEF were recorded between the 2 examiners.

3D RV Ejection Fraction

Reference values for the RVEF differ in the current literature, and normal RVEF values range from 45% to 66% in CMR- and computer tomography–derived data.[9–12] The authors decided to choose reference values for the RV ejection fraction from the most current guidelines of the American Society of Echocardiography.[13]

Thus, a 3D TEE-derived RVEF $\geq$45% was considered normal and a RVEF $<$45% was considered reduced.

RV Size

RV size was assessed in 3D TEE using the RV EDVI indexed to body surface area. A calculated EDVI was considered normal in males between 35 mL/m^2 and 87 mL/m^2 and in females between 32 mL/m^2 and 74 mL/m^2 following the current guidelines of the American Society of Echocardiography.[13]

Tricuspid Regurgitation

Tricuspid regurgitation was evaluated in a mid esophageal (ME) 4-chamber view and ME RV inflow-outflow view by color-flow Doppler and graded as mild (0º-Iº), moderate (IIº), or severe (IIIº) according to the vena contracta width and the direction and size of the tricuspid regurgitation (TR) jet.[14,15]

Statistical Analysis

Results are expressed as mean $\pm$ standard deviation (SD). To measure interrater agreement, the Cohen Kappa coefficient was calculated between clinicians evaluating the 2D images based on categorical/ordinal data[16] (IBM® SPSS® Statistics 23.0; IBM Corp, Armonk, NY). In order to minimize interrater variability among the 4 clinicians evaluating the 2D echo data, the majority rule was used.

Interrater 3D reliability between the datasets obtained from 2 different examiners were assessed using Cronbach's alpha correlation coefficient (IBM® SPSS® Statistics 23.0). Spearman's rank correlation coefficient was used in order to test the correlation between interval data (calculated RVEF) and ordinal data (visual assessment of RV function) (IBM®