Additional Cross-sectional Transesophageal Echocardiography Views Improve Perioperative Right Heart Assessment

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ABSTRACT

Background: Right heart failure is an important cause of perioperative morbidity and mortality, and transesophageal echocardiography (TEE) is crucial for its diagnosis. However, only four of the 20 cross-sectional views recommended in current guidelines for intraoperative TEE focus on the right heart. This study analyzed whether incorporating additional views into the standard TEE examination improves assessment of the right heart.

Methods: Sixty patients underwent standard TEE examination after induction of anesthesia. In addition, five views focusing on the right heart were acquired. Offline analysis tested: (1) whether the additional TEE views can be acquired as reliably as standard views including parts of the right heart; whether incorporating additional views improves the assessment of (2) eight or more right ventricular wall segments based on a predefined nine-segment model; (3) the tricuspid or pulmonary valve in two or more planes; and (4) transvalvular tricuspid and pulmonary flow in orthograde fashion.

Results: Additional views could be imaged as reliably (88%) as standard views (90%). Incorporating some of the additional views allowed the assessment of eight or more right ventricular segments in 59 (98%) *versus* 18 patients (30%) by the standard views alone, and of the pulmonary valve in two or more planes in 60 (100%) *versus* 15 patients (25%). Several additional views improved orthograde assessment of transvalvular pulmonary flow, but not of tricuspid flow.

Conclusions: The additional TEE views focusing on the right heart can be acquired as reliably as standard views. Incorporating three of them into the standard TEE examination improves comprehensive assessment of the right heart.

What We Already Know about This Topic

- In the intensive care unit, transesophageal echocardiography (TEE) reveals right ventricular dysfunction to be the cause of low cardiac output in nearly 50% of patients with myocardial failure after cardiac surgery. However, at present, TEE evaluation of the right heart largely consists of four standard views.
- This study assessed the value of five additional predefined TEE views of the right heart.

What This Article Tells Us That Is New

- Predefined additional cross-sectional TEE views focusing on the right heart cannot only be acquired as reliably as the standard TEE views, but incorporation of three of these views into the routine TEE examination improves comprehensive right heart assessment.

THE right ventricle plays an important role in the morbidity and mortality of patients with cardiopulmonary disease, both without surgery and in the perioperative setting.[1–3] In the operating room, right heart failure may be the cause of acute circulatory collapse, and transesophageal echocardiography (TEE) is crucial for its diagnosis and therapeutic guidance.[4–7] In the intensive care unit, TEE has revealed right ventricular dysfunction to be the cause of low cardiac output in nearly 50% of patients with cardiac failure after cardiac surgery.[2] Despite these facts, evaluation of the right heart has long been neglected in echocardiographic studies, and the recent guidelines for echocardiographic assessment of the right heart[1] mainly focus on transthoracic echocardiography. Updated guidelines for TEE by the American Society of Anesthesiology and the Society of Cardiovascular Anesthesiologists give evidence-based advice on indications for TEE in the perioperative period but do not recommend specific cross-sectional views.[8] Such recommendations were published in 1999 as guidelines for performing a comprehensive intraoperative multiplane TEE examination,[9] but only four of the 20 recommended views primarily focus on the

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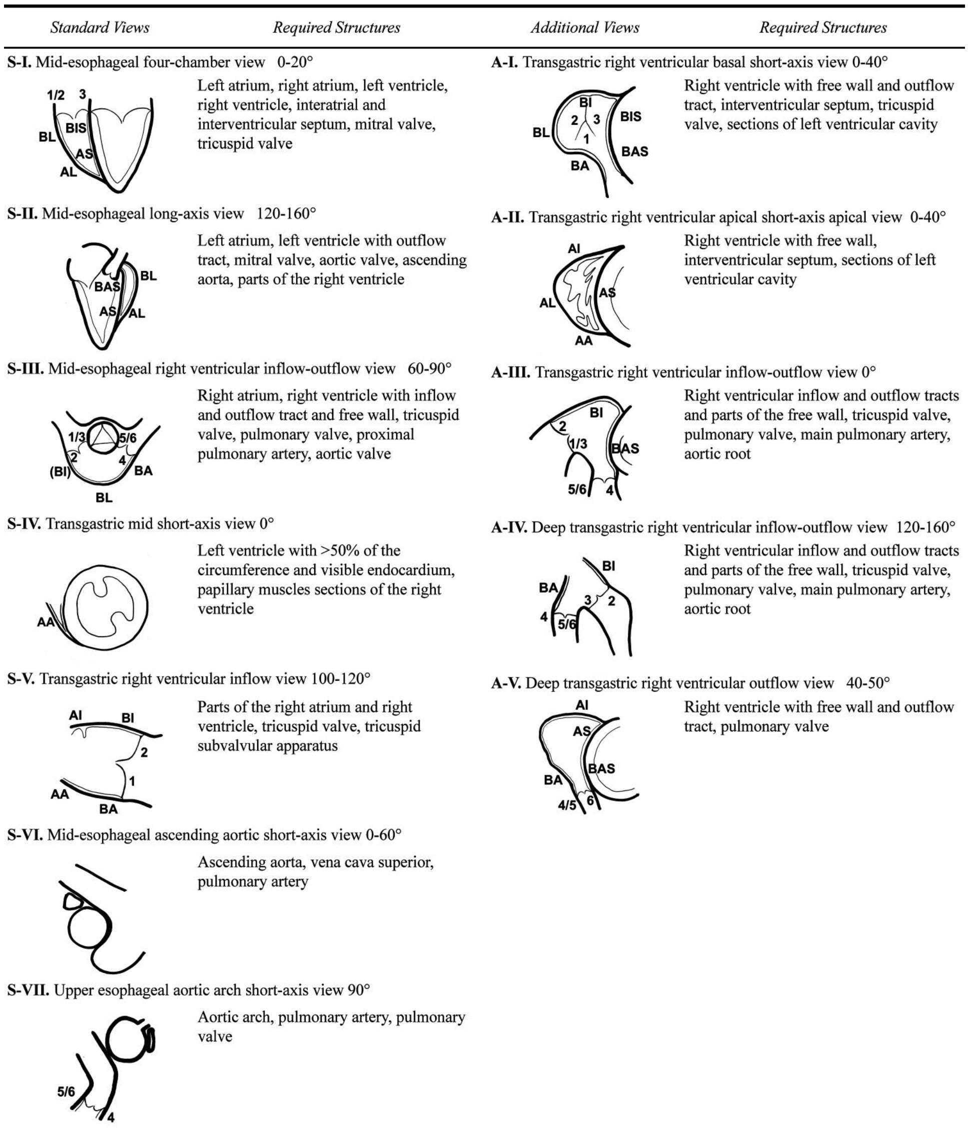

Fig. 1. Seven standard (S) transesophageal echocardiographic views[9] and five additional (A) views studied in 60 patients. Five basal segments: BA = basal anterior; BAS = basal anteroseptal; BI = basal inferior; BIS = basal inferoseptal; BL = basal lateral. Four apical segments: AA = apical anterior; AI = apical inferior; AL = apical lateral; AS = apical septal. Tricuspid valve: 1 = anterior cusp; 2 = posterior cusp; 3 = septal cusp. Pulmonary valve: 4 = anterior cusp; 5 = right cusp; 6 = left cusp.

right heart. As one or the other views may be of poor quality in some patients, these four views may often be insufficient for comprehensive evaluation of the right heart. The case of a patient in whom TEE failed to detect perforation of the right ventricle by a coronary sinus catheter supports the need for more TEE views focusing on the right heart.[10] Additional TEE views in combination with a right ventricle segment model should be useful for detecting and unambiguously describing the location of right ventricular pathology, *e.g.*, right ventricle wall perforation in the event of ischemia, interventional procedures, or pacemaker lead extractions. The limited number of views focusing on the right heart may also preclude imaging the right-sided valves in more than one cross-section, and obtaining a parallel intercept angle for evaluation of a valvular lesion.[11] For these reasons, echocardiographers have begun using additional transgastric TEE views for assessing the right heart (*e.g.*, the deep transgastric inflow-outflow view).[12] At our institution, we routinely monitor five additional views focusing on the right heart. However, the feasibility of these additional views and their value for improving monitoring of the right heart has not been prospectively studied.

The aim of this study was to assess the value of each of the five additional predefined TEE views (fig. 1) for imaging of the right heart. We hypothesized that: (1) the additional views can be assessed as reliably as seven standard TEE views that include parts of the right heart. Incorporating these additional views into the standard examination (2) improves the ability to assess at least 8 of 9 predefined right ventricular wall segments; (3) improves the ability to assess both the tricuspid valve and the pulmonary valve in two or more planes; and (4) improves the ability to assess transvalvular tricuspid flow and pulmonary flow in an orthograde fashion (*i.e.*, with an angle of 20 degrees or fewer between blood flow and Doppler ultrasound beam).

Materials and Methods

The study was approved by the local ethics committee (Ethikkommission beider Basel, Basel, Switzerland). Each patient gave written informed consent to the anesthetic treatment, which includes TEE as part of the routine monitoring for cardiac surgical patients, unless contraindications are present. Each patient also gave written informed consent to anonymous analysis and publication of data routinely obtained during routine perioperative care. Given these facts, an additional informed consent specific to this study was deemed unnecessary by the ethics committee.

Study Population and TEE Protocol

Sixty patients who underwent elective cardiac surgery at the University Hospital Basel were included. No patient included was subsequently excluded from study evaluation. All TEE examinations used for study analysis were performed by one single echocardiographer (JK) who studied consecutive patients whenever he was available in the operating room. Using a Philips iE 33 ultrasonographic system and an OmniPlane III or ×7–2t probe (Philips Medical Systems, Best, the Netherlands), the TEE examinations were performed after induction of general anesthesia but before opening of the sternum, simultaneously with the routine preoperative preparations. The TEE study protocol included seven cross-sectional views recommended by Shanewise *et al.*[9] plus five predefined additional views primarily focusing on the right heart (fig. 1). The time needed to record each cross-sectional view was measured. The study was completed as soon as the TEE protocol was finished. The data were digitally stored in an anonymous fashion on compact disc for subsequent offline analysis.

Offline Analysis of Echocardiographic Study Data

The feasibility of imaging each cross-sectional view included in the study was analyzed by checking whether the required structures predefined for each view were present (fig. 1.). A cross-sectional view was defined as sufficiently imaged if all or all but one of the predefined required structures were visible. A cross-sectional view was defined as insufficiently imaged if two or more required structures were not visible.

The feasibility of imaging all parts of the right ventricular wall was based on a nine-segment model of the right ventricle designed specifically for this analysis. The model was based on three important aspects: the anatomic division of the right ventricle into an inflow tract (sinus), an apical trabecular part, and an outflow tract (conus).[13,14] The recommendation given in the American Society of Echocardiography/Society of Cardiovascular Anesthesiologists guidelines for performing a comprehensive intraoperative multiplane TEE examination uses the terms basal, apical, anterior, inferior, and right ventricular outflow tract for localizing specific regions of the right ventricular wall.[9] One needs to acknowledge that the right ventricle is not uniformly perfused by the right coronary artery.[1] Based on these aspects and with the goal to allow for a detailed and systematic analysis, we subdivided the right ventricular wall into nine segments: into three basal segments of the inflow tract and two basal segments of the outflow tract, and into four apical wall segments of the trabecular component. Analogous to the left ventricle,[9] we numbered the wall segments from basal to apical and in clockwise direction from anteroseptal/septal to anterior, lateral, and inferior, resulting in the following wall segments: (1) basal anteroseptal and (2) basal anterior segments of the outflow tract, (3) basal lateral, (4) basal inferior, and (5) basal inferoseptal segments of the inflow tract, (6) apical septal, (7) apical anterior, (8) apical lateral, and (9) apical inferior segments of the apical trabecular component (fig. 2). Right ventricular wall segments potentially visible in each of the cross-sectional views were defined before beginning the study (fig. 1). During the offline study analysis, the readers analyzed each cross-section and evaluated each potentially visible segment, determining whether it was sufficiently imaged. Identical to our previously published definition for the left ventricular wall segments, a segment was regarded as sufficiently imaged if at least 50% of the endocardial and epicardial borders of a segment were visible, or if at least 90% of the endocardial border was visible throughout the cardiac cycle whenever the epicardium was not visible.[15] After completion

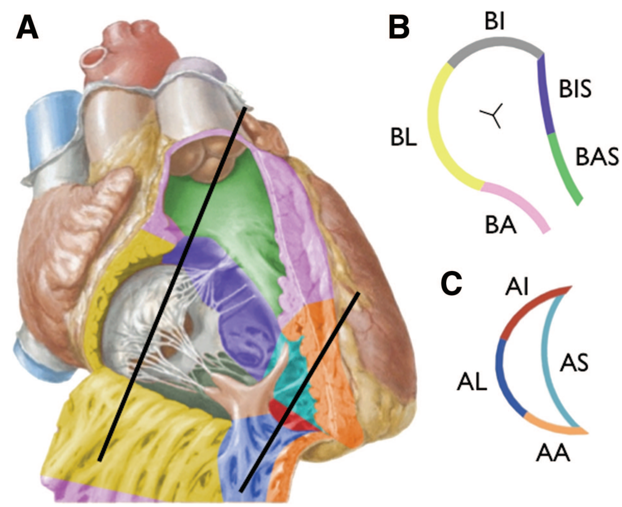

Fig. 2. Anatomical model of the transgastric basal and apical short-axis views. (*A*) Right ventricular wall segments. (*B*) Five basal segments: BA = basal anterior; BAS = basal anteroseptal; BI = basal inferior; BIS = basal inferoseptal; BL = basal lateral. (*C*) Four apical segments: AA = apical anterior; AI = apical inferior; AL = apical lateral; AS = apical septal. Reprinted with permission from netterimages.com.

of the readings, feasibility of imaging the right ventricular walls was analyzed by comparing how many of the predefined right ventricular segments were visible in the standard views alone *versus* in the standard plus additional views.

The feasibility of imaging the right ventricular valves in two or more planes was based on an analysis of each cross-sectional view visualizing the tricuspid and/or the pulmonary valve. A valve was considered as sufficiently imaged in a view if at least two cusps were visible during systole and diastole. After completion of the readings, feasibility of imaging the right ventricular valves in two or more planes was analyzed by comparing how frequently the tricuspid and the pulmonary valves were visible in two or more views when the standard views alone *versus* the standard plus additional views were considered.

The feasibility of orthograde imaging of transvalvular flow was based on offline measurements of the angle between blood flow and the Doppler beam. Transvalvular flows were defined as adequately assessed (*i.e.*, in an orthograde fashion) if the angle between blood flow and Doppler beam was 20 degrees or fewer. In addition, adequate assessment of transvalvular flow required that the valve was sufficiently visible. After completion of the readings, feasibility of orthograde imaging of transvalvular flow was analyzed by comparing how frequently the tricuspid and the pulmonary transvalvular flow were imaged in an orthograde fashion when the standard views alone *versus* the standard plus additional views were considered.

All analyses were performed offline and independently by two experienced echocardiographers (JK and KS). Contradictory readings by the two readers were solved by a joint consensus evaluation. These consensus readings were used for subsequent analysis. If the two readers reached no consensus, the segment, valve, or flow was regarded as insufficiently imaged.

Statistical Analysis

Continuous variables are presented as mean ± SD, and dichotomous variables as numbers (percentages). Fisher exact test was used to analyze dichotomous variables (*e.g.*, feasibilities of imaging the standard *vs.* the additional cross-sectional views).

The number of segments that could be visualized by the standard views was compared with the number visualized by the standard plus additional views using the Wilcoxon signed-rank test. The number of patients in whom at least eight segments could be visualized by the standard views was compared with the number visualized by the standard plus additional views using McNemar test. McNemar test was also used to compare the number of patients in whom the pulmonary and the tricuspid valve could be visualized in two or more planes by the standard *versus* the standard plus additional views, and to compare the number of patients in whom transvalvular flow could be imaged in an orthograde fashion. The κ coefficient was calculated to assess inter- and intraobserver agreement of the two readers of the echocardiographic data.

All *P*-value assessments were two-tailed, and $P \leq 0.05$ was considered statistically significant. All analyses were performed using the SPSS 16.0/17.0 for Macintosh (SPSS Inc., Chicago, IL).

The sample size calculation was based on pilot data suggesting that the standard views visualize eight or more ventricular wall segments in approximately 50% of patients only. Using the McNemar test, we calculated that a sample of 60 patients would provide a power of 90% to show at an α level of 0.05 in a two-tailed test that 40% of the population will switch from − to + (*i.e.*, from less than eight visible segments to eight or more visible segments), whereas a proportion of 0.1 of the population will switch from + to −. This sample size also provided sufficient power to test the three other study hypotheses.

Table 1. Characteristics of the 60 Study Patients

Characteristics	Patients (No. = 60)
Female gender	12 (20)
Age (years)	69 ± 10
Weight (kilogramm)	78 ± 15
Height (centimeter)	169 ± 16
ASA physical status classification III: IV	54:6
Chronic obstructive pulmonary disease	4 (7)
Known pulmonary hypertension	3 (5)
Type of surgery	—
CABG	35 (58)
CABG + aortic valve replacement	11 (18)
CABG + mitral valve replacement	1 (2)
Aortic valve replacement	9 (16)
Composite graft	2 (3)
Percutaneous aortic valve replacement	2 (3)

Values are number (%) or mean values ± standard deviation. ASA = American Society of Anesthesiologists; CABG = coronary artery bypass grafting.

Results

Patient characteristics are described in table 1.

Feasibility of Imaging the Cross-sectional Views

Six of the seven standard cross-sectional views and four of the five additional views could be imaged in sufficient quality in more than 80% of patients (fig. 3). A low feasibility was found for the standard upper esophageal aortic arch short-axis view (48%), and for the additional transgastric right ventricular inflow-outflow view (66%). Average feasibility was similar for the seven standard views (48–100%, mean 90%) and for the five additional views (66–98%, mean 88%).

The average time needed for acquiring each of the standard and additional views focusing on the right ventricle was 59 s (29–69 s). The average time needed for acquiring the two views focusing on the great vessels was substantially lon-

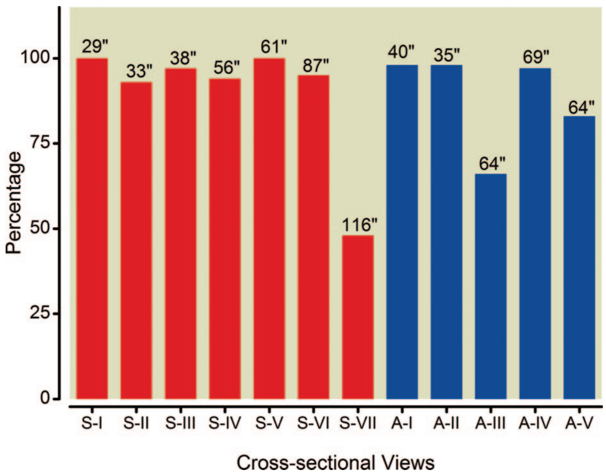

Fig. 3. Feasibility of imaging seven standard (S) cross-sectional views and five additional (A) cross-sectional views (%), and the time required to obtain each view (seconds). The cross-sectional views are described in fig. 1.

ger (*i.e.*, 87 s for the mid-esophageal ascending aorta short-axis view, and 116 s for the upper esophageal aortic arch short-axis view) (fig. 3).

Feasibility of Imaging Right Ventricular Wall Segments

By using the standard views, eight or nine right ventricular wall segments could be imaged in 18 patients (30%). By adding one of the additional views, the apical transgastric right ventricular short-axis view, eight or nine segments could be imaged in 59 patients (98%) ($P < 0.001$). Table 2 shows the percentage in whom each right ventricular segment could be imaged by each view. The standard views visualized the five basal right ventricular segments and the apical lateral and septal segments in 80–100% of patients, but the apical anterior and inferior segments in less than 40%. Addition of the transgastric apical right ventricular short-axis view (fig. 4) significantly improved visualization of the apical anterior and inferior segments ($P < 0.0001$ for both segments).

Feasibility of Imaging the Right Ventricular Valves in Two or More Planes

The standard views visualized the tricuspid valve in two or more planes in 58 patients (97%). Adding additional views did not improve this percentage. The pulmonary valve was visualized by the standard views in two or more planes in 15 patients (25%) (table 3). Adding any of the additional views to the standard views significantly improved visualization of the pulmonary valve in two or more planes (table 3), and adding the two deep transgastric views (fig. 4) to the standard views allowed visualization of the pulmonary valve in two or more planes in all 60 patients ($P < 0.001$ *vs.* standard views alone).

Feasibility of Orthograde Imaging of Transvalvular Flow

The standard views allowed acquiring tricuspid transvalvular blood flow in an orthograde fashion in 31 patients (51%), and the additional views provided no improvement.

Table 2. Feasibility (%) of Imaging the Nine Right Ventricular Wall Segments in Five Standard Cross-sectional Views and in Five Additional Views in 60 Patients

	Basal Segments					Apical Segments			
Cross-sectional Views	BAS	BA	BL	BI	BIS	AS	AA	AL	AI
S-I. Mid-esophageal four chamber view 0–20 degrees	—	—	80	—	92	83	—	80	—
S-II. Mid-esophageal long axis view 120–160 degrees	90	—	95	—	—	12	—	12	—
S-III. Mid-esophageal right ventricular inflow-outflow view 60–90 degrees	—	98	87	95	—	—	—	—	—
S-IV. Transgastric mid short-axis view 0 degrees	—	—	—	—	—	—	17	—	—
S-V. Transgastric right ventricular inflow view 100–120 degrees	—	88	—	98	—	—	31	—	39
A-I. Transgastric right ventricular basal short-axis view 0–40 degrees	90	97	97	100	100	—	—	—	—
A-II. Transgastric right ventricular apical short-axis 0–40 degrees	—	—	—	—	—	98	90	98	97
A-III. Transgastric right ventricular inflow-outflow view 0 degrees	—	52	—	97	—	—	—	—	—
A-IV. Deep transgastric right ventricular inflow-outflow view 120–160 degrees	—	93	—	92	—	—	—	—	—
A-V. Deep transgastric right ventricular outflow view 40–50 degrees	88	93	—	—	—	88	—	—	93

The cross-sectional views are described in fig 1.

A = additional; AA = apical anterior; AI = apical inferior; AL = apical lateral; AS = apical septal; BA = basal anterior; BAS = basal anteroseptal; BI = basal inferior; BIS = basal inferoseptal; BL = basal lateral; S = standard.

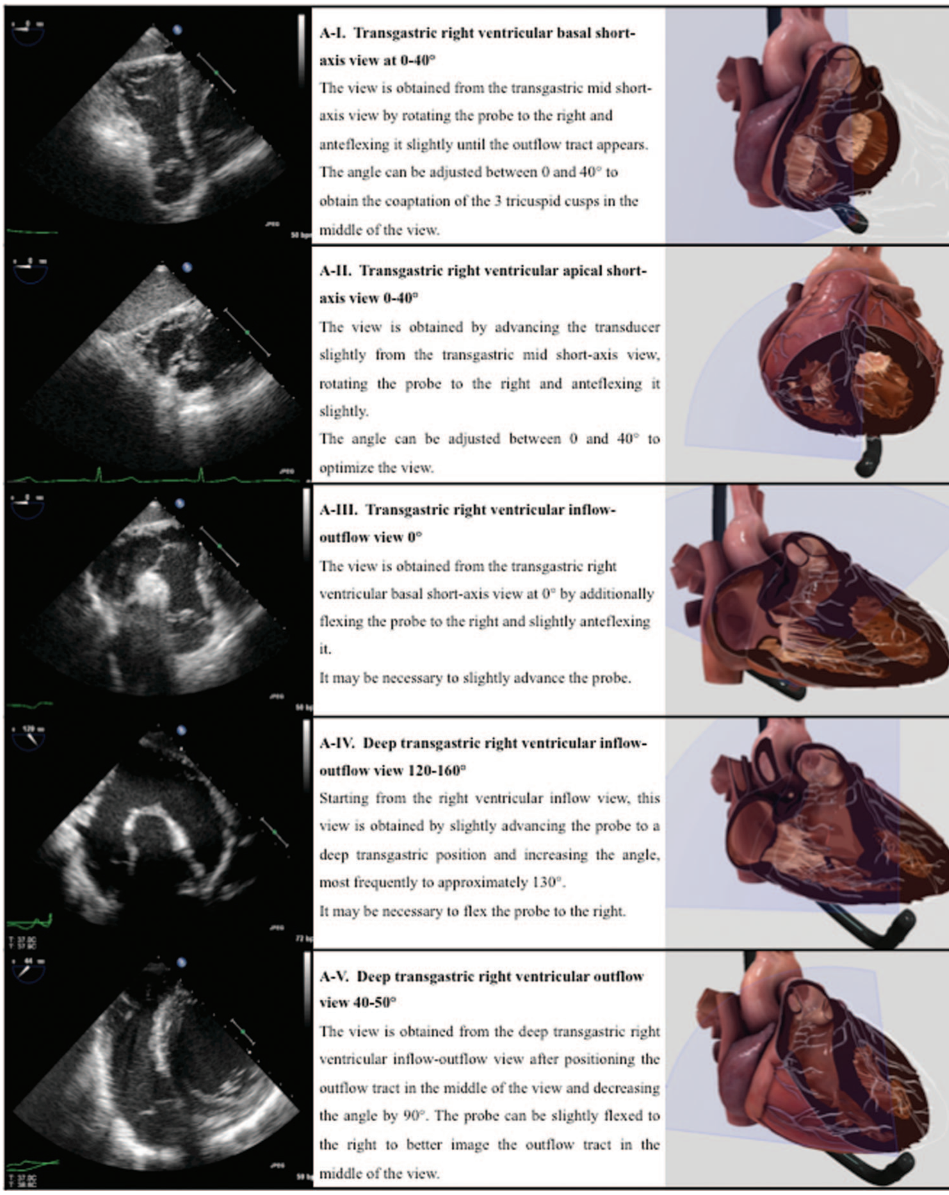

Fig. 4. Still frames and corresponding images of an anatomical model of five additional transesophageal echocardiography cross-sectional views and descriptions on how to obtain these views. The images of the anatomical model with slice planes have been created with a HeartWorks transesophageal echocardiography simulator, courtesy of Inventive Medical Ltd., London, United Kingdom.

Pulmonary transvalvular blood flow was acquired in an orthograde fashion by the standard views in 17 patients (28%) (table 3). Each of the three additional views that visualize the pulmonary valve enabled orthograde assessment of transvalvular pulmonary blood significantly more frequently than each of the standard views ($P < 0.01$). Adding any combination of two additional views visualizing the pulmonary valve to the standard views significantly improved the assessment of pulmonary transvalvular blood flow to 51 patients (85%) ($P < 0.0001$). The addition of all three additional views allowed orthograde assessment of pulmonary transvalvular blood flow in 53 patients (88%).

Inter- and Intraobserver Agreement

The κ coefficients for inter- and intraobserver agreement were 0.70 and 0.82, respectively, for feasibility of imaging the cross-sectional views. The κ coefficients were 0.63 and 0.78 for the analysis of visualization of right ventricular wall segments, 0.80 and 0.83 for analysis of right ventricular valves, and 0.83 and 0.86 for assessment of transvalvular flow. Contradictory readings were made in 5% of analyses for feasibility of the cross-sectional views, in 12% of analyses of the right ventricular wall segments, in 6% of analyses of the right ventricular valves, and in 8% of analyses of transvalvular flow. Agreement could be achieved by a joint consensus evaluation in all cases.

Table 3. Feasibility (%) of Imaging the Pulmonary Valve, and of Orthograde Imaging of Transvalvular Pulmonary Flow in 60 Patients

	Imaging of the Pulmonary Valve		Orthograde Imaging of Transvalvular Pulmonary Flow	
Cross-sectional View	In 1 Plane by the Single View	In 2 or More Planes, Single View Plus All Standard Views	Single View	Single View Plus All Standard Views
S-III. Mid-esophageal right ventricular inflow-outflow view 60–90 degrees	42 (70%)	15 (25%)	0 (0%)	17 (28%)
S-VI. Mid-esophageal ascending aortic short-axis view 0–60 degrees	11 (18%)	15 (25%)	11 (18%)	17 (28%)
S-VII. Upper esophageal aortic arch short-axis view 90 degrees	12 (20%)	15 (25%)	12 (20%)	17 (28%)
A-III. Transgastric right ventricular inflow-outflow view 0 degrees	31 (52%)	31 (52%)	27 (45%)	37 (62%)
A-IV. Deep transgastric right ventricular inflow-outflow view 120–160 degrees	47 (78%)	41 (68%)	41 (68%)	48 (80%)
A-V. Deep transgastric right ventricular outflow view 40–50 degrees	40 (67%)	38 (63%)	39 (65%)	44 (73%)

A = additional; S = standard.

Discussion

This prospective study shows that several additional TEE cross-sectional views focused on the right ventricle can be acquired as reliably as the standard TEE views. Adding just one of these additional views to the standard TEE views markedly improves the ability to assess at least eight of the nine predefined right ventricular wall segments. Furthermore, adding two different additional views to the standard views markedly improves the ability to assess the pulmonary valve in two or more planes. Finally, the study found that adding these latter two views to the standard views improves the ability to assess transvalvular pulmonary flow within 20 degrees or fewer between blood flow and Doppler ultrasound beam.

The feasibility of assessing right ventricular wall segments was based on a nine-segment model of the right ventricle specifically created for allowing a detailed scientific analysis. We are aware that such division into nine segments is somewhat arbitrary, although the model was developed based on the anatomical structures of the right ventricle and in similarity to the left ventricle.[9,16] Several reasons prompted us to create this segmental model, as explained in Materials and Methods. In short, the segmental model considers the anatomic division of the right ventricle into inflow tract, trabeculated apical part, and outflow tract[12,13]; it applies recommended terms for topographic localization in the right ventricle, as given in current guidelines for performing a intraoperative TEE examination[9]; and it uses a segmental nomenclature of the right ventricular walls in correlation to the coronary supply,[17] as also recommended in recent international guidelines for transthoracic echocardiographic assessment of the right ventricle in adults.[1] The model should stimulate the awareness that not all segments of the right ventricle are supplied in identical fashion by the right coronary artery. Perfusion of the anteroseptal wall and – to a minor and varying degree – of parts of the anterior wall originates from the left anterior descending coronary artery, whereas marginal branches of the right coronary artery supply most parts of the anterior and the lateral wall. The posterior descending artery of the right coronary artery supplies the inferior wall and, in most patients, the inferoseptal wall.[17] The outflow tract receives blood supply from the conal artery. This artery has a separate ostial origin in 30% of patients, which may explain observations of preserved myocardial function of the outflow tract despite a proximal occlusion of the right coronary artery.[14,18] An additional aspect of potential importance is collateral blood supply through the moderator band artery that originates from the left anterior descending coronary artery, and which may determine the size of right ventricular infarction.[19]

This study found that adding the apical transgastric right ventricular short-axis view (fig. 1) to the standard views improves the feasibility to assess at least eight of the nine predefined right ventricular wall segments. The standard cross-sectional views reliably allow assessing the five basal right ventricular segments but frequently fail to visualize the anteroapical and inferoapical segments. This failure is concerning, because previous studies have demonstrated monitoring of the apical right ventricular wall to be of clinical importance. For example, acute pulmonary embolism as well as right ventricular infarction may result in severe hypokinesis of the basal and mid right ventricular wall with preserved apical wall motion.[20,21] Another study has reported that apical wall motion may be depressed in patients with pulmonary hypertension not caused by pulmonary embolism.[22] Furthermore, a study in patients with arrhythmogenic right ventricular dysplasia has found predominant involvement of trabecular apical segments.[23] Finally, it may be important to note that physiologic differences in regional wall motion need to be considered when contraction of basal and apical segments of the right ventricle are compared: Studies using tissue Doppler imaging in healthy individuals have found markedly higher systolic velocities in the basal right ventricular segments than in the apical segments.[24,25]

Adequate echocardiographic evaluation of valvular function requires the ability to image each valve in two or more planes, as a single view may miss an eccentric regurgitant jet.[11] Our analysis on the feasibility of assessing the right-sided valves found that the standard views allowed imaging of the tricuspid valve in two or more planes in 58 patients (97%) but of the pulmonary valve in only 15 patients (25%).

According to the TEE guidelines, the pulmonary valve can be assessed in two of the standard TEE cross-sectional views.[9] In addition, the valve may be occasionally imaged by the mid-esophageal ascending aortic short-axis view at 0–60 degrees. However, the feasibility of these views for imaging the valve has not been systematically analyzed so far. The present study found that these standard views are unequally useful for imaging the pulmonary valve: The valve was visualized reliably (70%) by the mid-esophageal right ventricular inflow-outflow view, but rarely (20%) by the upper esophageal aortic arch short-axis view and the mid-esophageal ascending aortic short-axis view (18%). The low image acquisition rate in conjunction with the long time required for obtaining it (fig. 3) indicates that the upper esophageal aortic arch short-axis view is difficult to acquire if adequate visualization of the pulmonary valve is required. The mid-esophageal ascending aortic short-axis view could be acquired in most patients, but – as described in the guidelines by Shanewise *et al.*[9] – most frequently without visualization of the pulmonary valve. These findings explain why the standard views did not allow for assessing the pulmonary valve in two or more planes in most patients.

Visualization of the pulmonary valve in two planes was feasible in all 60 patients by adding the two deep transgastric cross-sectional views, *i.e.*, the right ventricular inflow-outflow view at 120–160 degrees and the right ventricular outflow view at 40 degrees (fig. 1), to the standard views. As echocardiographic assessment of valvular function needs to be based on findings obtained from different angles, we, therefore, recommend incorporating these two additional deep transgastric views into the standard TEE examination. The additional transgastric right ventricular inflow-outflow view may also improve imaging of the pulmonary valve (fig. 3, table 3). Its usefulness is limited by an acquisition rate that is lower than that of the additional deep transgastric views but is still higher than the acquisition rate of the standard upper esophageal aortic arch short-axis view (fig. 3).

Our analysis on the feasibility of orthograde imaging of transvalvular flow revealed that the additional views did not improve orthograde assessment of transvalvular blood flow through the *tricuspid* valve. Its assessment remained unfeasible in approximately half of all patients.

Pulmonary transvalvular blood flow was acquired by the standard views only in a small percentage (28%) of patients. It may be important to note that the mid-esophageal ascending aortic short-axis view allowed assessment of flow in the common pulmonary artery in most patients, but – in the absence of visualization of the pulmonary artery – transvalvular flow in only a small minority. Addition of any of the three additional cross-sectional views visualizing the pulmonary valve improved orthograde assessment of transvalvular pulmonary flow. Any combination of two of these additional views improved acquisition of orthograde transvalvular flow to 51 patients (85%). Addition of all three additional views to the standard views improved orthograde assessment of transvalvular pulmonary flow to 53 patients (88%).

Some limitations of our study need to be considered. First, the cross-sectional views required for this study were acquired before opening of the chest and were not acquired again after cardiopulmonary bypass or closure of the chest. Therefore, we cannot exclude that image quality of some views may be reduced after surgery (*e.g.*, by interference of the ultrasound beam with pericardial drainage tubes). Second, we have studied the feasibility of cross-sectional views and their ability for visualizing different parts of the right heart. However, it was not in the focus of this study to evaluate whether using these views is clinically useful for improving patient care and outcome. Third, interinvestigator agreement for visualization of the right ventricular wall segments is only moderate, as indicated by $\kappa = 0.63$. This finding may reflect the difficulty to consistently image the right ventricular endocardium and epicardium. Finally, the present study did not include three-dimensional imaging, which may further improve assessment of the right heart in the future.

In conclusion, we found that the predefined additional cross-sectional TEE views focusing on the right heart can be acquired as reliably as the standard TEE views. Incorporating three of these views (fig. 4) into the routine TEE examination improves comprehensive assessment of the right heart. The apical transgastric right ventricular short-axis view improves assessment of the right ventricular wall by better visualizing the apical segments. The deep transgastric right ventricular inflow-outflow view and the deep transgastric right ventricular outflow view improve the ability to assess the pulmonary valve in two or more planes and to assess transvalvular blood flow through the pulmonary valve in an orthograde fashion. These findings suggest that these additional TEE views should be routinely monitored when performing a comprehensive intraoperative multiplane TEE examination.

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