Role of Echocardiography for the Perioperative Assessment of the Right Ventricle

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Abstract

Purpose of Review This review aims to highlight the perioperative echocardiographic evaluation of right ventricular (RV) function with strengths and limitations of commonly used and evolving techniques. It explains the value of transthoracic echocardiography (TTE) and transesophageal echocardiography (TEE) and describes the perioperative changes of RV function echocardiographers should be aware of.

Recent Findings RV dysfunction is an entity with strong influence on outcome. However, its definition and assessment in the perioperative interval are not well-defined. Moreover, values assessed by TTE and TEE are not interchangeable; while some parameters seem to correlate well, others do not. Myocardial strain analysis and three-dimensional echocardiography may overcome the limitations of conventional echocardiographic measures and provide further insight into perioperative cardiac mechanics.

Summary Echocardiography has become an essential part of modern anesthesiology in patients with RV dysfunction. It offers the opportunity to evaluate not only global but also regional RV function and distinguish alterations of RV contraction.

Keywords Echocardiography · Transesophageal · Transthoracic · Right ventricular function · Perioperative assessment

Introduction

Echocardiography is an essential part of modern anesthesia in patients undergoing the entire spectrum of cardiac surgery [1••, catheter-based cardiac procedures [2], and in high-risk non-cardiac surgery [3]. Although the right ventricle (RV) and its contribution to cardiac physiology and patient outcome has been neglected for a long time, the importance of RV function has been recognized in recent years in surgery [4] and non-surgery patients [5]. Perioperative RV dysfunction or failure has a wide range of etiologies and is a complex and dynamic entity [4]. It is a predictor of morbidity and mortality in various non-cardiac [6] and cardiac surgery procedures [7, 8], where it seems to be a strong predictor of mortality independent from the estimated surgical risk [8•].

Beyond cardiac magnetic resonance tomography (cMRT), as gold standard of cardiac imaging, echocardiography and catheter-based measurements offer the opportunity to monitor RV function intraoperatively. However, only echocardiography allows the operator to evaluate RV morphology and global function as well as regional differences and pathologies of associated structures. The RV has particular anatomical and functional characteristics that need to be addressed during echocardiographic evaluation and decision-making [9–11]. Moreover, the surgical or interventional procedure can have influence on the perioperative course of RV function [4, 9, 12] making assessment challenging.

There are several conventional echocardiographic parameters commonly used for evaluation of RV function, with specific strengths and limitations in the perioperative period. Furthermore, there are upcoming techniques for echocardiographic assessment of RV function with promising features.

This review aims to describe the current state of the art echocardiographic assessment of perioperative RV function and give further insight into evolving techniques in this field of research.
Anatomical and Pathophysiological Background

A profound understanding of RV anatomy and pathophysiology helps to understand diagnostic and management options.

RV Anatomy

The RV has a singular and complex form [9]. It seems triangular from a lateral view and crescent-shaped in a cross-sectional view. The RV has a thin free wall that is formed of transverse fibers, with sparse subendocardial longitudinal fibers [13]. The interventricular septum forms its medial border containing oblique helical fibers that cross each other at 60° [13]. Appearing smaller than the left ventricle (LV), the RV has a larger volume than the LV [9, 13], and its mass is only about 1/6 of the mass of the LV [14]. The RV can be subdivided into three parts: the inflow tract, the trabeculated apical portion, and the outflow tract [9, 14].

RV Pathophysiology

The main function of the RV is to receive systemic venous blood and eject it into the pulmonary circulation. Under normal circumstances, the RV is coupled to a low pressure, highly distensible arterial system [14, 15]. The RV is linked in series with the LV. In the absence of shunts and valvular regurgitation, the stroke volume of the RV is equivalent to the stroke volume of the LV. However, because of the greater end-diastolic volume of the RV, the right ventricular ejection fraction (RV EF) is lower than the left ventricular ejection fraction (LV EF) [9, 14].

Numerous mechanisms are essential for RV contraction. Perhaps the most important mechanism is the bellows-like inward motion of the RV free wall. Other important mechanisms contain the contraction of the longitudinal fibers initiating the shortening of the long axis and movement of the tricuspid annulus toward the apex [14]. The typical contraction of the RV is sequential, starting with the inflow tract (sinus), proceeding with the heavily trabeculated apical portion, and ending with the contraction of the outflow tract (infundibulum), delayed by 25–50 ms [9, 13, 14].

Although the interventricular septum (IVS) does not exclusively reflect RV function, it is of great importance for RV geometry and function. Approximately 30 to 40% of RV stroke volume is dependent on LV contraction by bulging of the ventricular septum into the RV cavity [16], explaining the great importance of IVS for RV function in systole and diastole [17].

Definition of RV Dysfunction and Failure

Although there is no generally accepted definition of RV failure, it can be defined as a combination of systemic arterial hypotension with increased right ventricular filling pressures [18]. Another common definition focuses on the functional approach and defines RV failure as the inability of the RV to provide adequate blood flow through the pulmonary circulation at normal central venous pressure [19].

RV dysfunction definitions vary in the literature. According to the current guidelines of the American Society of Echocardiography (ASE) and the European Association of Cardiovascular Imaging (EACVI), RV dysfunction is present when the echocardiographic parameters used to quantify RV function are less than the lower or greater than the higher reference value of the normal range (mean ± 2 × standard deviation), pointing out that available validated data are insufficient for the classification of abnormal categories into mild, moderate, and severe [10, 11]. Therefore, based on the current guidelines, only a dichotomous approach to RV impairment is feasible.

Echocardiography

Evaluation of RV function needs multiple acoustic windows, and the report should present an assessment based on both qualitative and quantitative parameters [10, 11]. Qualitative evaluation of RV function may be performed by experienced operators [20, 21], but, may have random results [11]. The guidelines on RV function assessment focus on transthoracic echocardiography (TTE), while guidelines on transesophageal echocardiography (TEE) mainly neglect the evaluation of RV function [3, 22]. Moreover, parameters assessed by TTE and TEE are not interchangeable, and normal values of RV function assessed by TEE are not well-established [23].

RV Systolic Function

Conventional Echocardiographic Parameters

Several RV parameters are recommended by current guidelines (Table 1), each of these with its own strengths and limitations, particularly regarding the perioperative interval (Table 2).

Linear Measurements Quantitation of RV dimensions is essential and reduces interobserver variability compared with visual assessment alone [10]. These parameters are simple, easy to obtain, fast, and well-validated [10]. However, evaluation by two-dimensional echocardiography is challenging because of the complex geometry of the RV, having a high intra- and interobserver variability depending on the assessed
RV dimensions are best estimated from a RV-focused four-chamber view, with a diameter of > 41 mm at base and > 35 mm at mid-level indicating RV dilatation [10]. RV wall thickness, performed in end-diastole, below the tricuspid annulus is an easy to perform single-site measurement, with values of > 5 mm suggesting RV free wall hypertrophy.

**Tricuspid Annular Plane Systolic Excursion (TAPSE)** TAPSE is a measure of longitudinal movement of the lateral tricuspid annulus to the apex during systole. Although it is a regional measure, it correlates with global systolic RV function [11, 25] and patient outcome in different clinical conditions [4]. TAPSE < 17 mm is highly suggestive of RV systolic dysfunction [10]. It is an easy to obtain, but angle-dependent parameter of RV longitudinal function with excellent temporal resolution measured by M-mode echocardiography [10, 11]. Therefore, alignment of the M-mode cursor with the longitudinal motion of the lateral tricuspid annulus should be achieved. This is simply performed in a four-chamber view by TTE [10] and needs an alternative approach by using TEE [1], since adequate alignment in TEE mid-esophageal four-chamber view is not feasible. Possible solutions addressing this issue are the use of alternative views with superior alignment or the use of alternative technologies [1]. Alternative views with superior alignment exist for visualization of the RV [22]. Particularly, the modified deep transgastric view focusing the right ventricle and the transgastric RV inflow view has been evaluated in the literature, however, showing underestimation of TAPSE by TEE using these alternative views in comparison to TAPSE by TTE using an apical four-chamber view [26, 27]. Therefore, alternative and less angle-dependent techniques seem more promising.

Measurement of TAPSE by anatomic M-mode which evaluates two-dimensional pixel samples along a freely positioned cursor line presented increased precision [26, 28]. A further approach is to measure TAPSE with speckle-tracking echocardiography, which is mainly angle-independent [28, 29]. First investigations showed promising and unbiased results; however, there seems to be doubt about precision and reliability [29, 30]. Moreover, TAPSE may not be an optimal parameter in the perioperative setting of cardiac surgery [31]. Several trials reported about reduced TAPSE after cardiac surgery, explaining this condition with pericardiotomy [32] or surgery and extracorporeal circulation [33], while global RV function was preserved. Therefore, the accurate assessment of perioperative RV function in cardiac surgery patients with this parameter is highly questionable.

**Tricuspid Annular Systolic Velocity (RV S’)** RV S’ has a lot of likeness with TAPSE and showed also to correlate with global RV function and patient outcome [10, 11, 25]. An RV S’ velocity less than 9.5 cm/s indicates RV systolic dysfunction measured by TTE in awake spontaneous breathing patients.

### Table 1 Reference and abnormal values of right ventricular function, assessed by TTE in awake, spontaneously breathing patients

| Parameter | Mean ± SD | Abnormal |
|-----------|-----------|----------|
| Systolic function | | |
| RVEDD basal (mm) | 33 ± 4 | > 41 |
| RVEDD mid-level (mm) | 27 ± 4 | > 35 |
| TAPSE (mm) | 24 ± 3.5 | < 17 |
| RV S’ (cm/s) | 14.2 ± 2.3 | < 9.5 |
| RV FAC (%) | 49 ± 7 | < 35 |
| RV MPI | 0.26 ± 0.085 (PW-Doppler) | > 0.43 (PW-Doppler) |
| | 0.38 ± 0.08 (TDI) | > 0.54 (TDI) |
| 3D-RV EF (%) | 58 ± 6.5 | < 45 |
| 2D-RV FWS | −29 ± 4.5 | > - 20 |
| 3D-RV FWS | Not defined | Not defined |
| Diastolic function | | |
| E/At | 1.4 ± 0.3 | < 0.8 or > 2.0 |
| e’ (TDI) | 14.0 ± 3.1 | < 7.8 |
| E/e’ | 4.0 ± 1.0 | > 6.0 |

Adopted from Lang et al. [10] and Badano et al. [54]

**RVEDD**, right ventricular end-diastolic diameter; **TAPSE**, tricuspid annular plane systolic excursion; **RV S’**, tricuspid annular systolic velocity; **RV FAC**, right ventricular fractional area change; **RV MPI**, right ventricular myocardial performance index; **3D-RV EF**, three-dimensional right ventricular ejection fraction; **2D-RV FWS**, two-dimensional derived right ventricular free wall strain; **3D-RV FWS**, three-dimensional derived right ventricular free wall strain; **Et**, peak velocity of early tricuspid inflow; **At**, peak velocity of late tricuspid inflow; **TDI**, tissue Doppler imaging.
## Table 2: Strengths and limitations of parameters of RV function assessment

| Parameter                  | Strength                                      | Limitation                                               | Perioperative aspects / TEE                      |
|----------------------------|-----------------------------------------------|----------------------------------------------------------|--------------------------------------------------|
| **Systolic function**      |                                               |                                                          |                                                  |
| RVEDD basal (mm)           | Easy to obtain                                | Underestimation of size                                  | No validated data                                 |
|                            | Simple and fast                               | Dependent on view and angle                              |                                                  |
|                            | Large amount of published data                |                                                          |                                                  |
| RVEDD mid-level (mm)       | Easy to obtain                                | Angle-dependent                                          |                                                  |
|                            | Simple and fast                               | Regional longitudinal function                           |                                                  |
|                            | Established prognostic value, Validated       |                                                          |                                                  |
| TAPSE (mm)                 | Easy to obtain                                | Angle-dependent                                          |                                                  |
|                            | Simple and fast                               | Regional longitudinal function                           |                                                  |
|                            | Established prognostic value, Validated       |                                                          |                                                  |
|                            | Less load-dependent than TAPSE, Validated     |                                                          |                                                  |
| RV S’ (cm/s)               | Easy to obtain                                | Angle-dependent                                          |                                                  |
|                            | Simple and fast                               | Regional longitudinal function                           |                                                  |
|                            | Less load-dependent than TAPSE, Validated     |                                                          |                                                  |
| RV FAC (%)                 | Easy to obtain                                | Neglects RV outflow tract                                | Good agreement between TTE and TEE               |
|                            | Simple and fast                               | Only fair interobserver reproducibility                  | Predicts outcome in cardiac surgery              |
|                            | Established prognostic value, Validated       |                                                          |                                                  |
|                            | Longitudinal and transversal contraction      |                                                          |                                                  |
| RV MPI                     | Single beat recording                         | Unreliable in elevated right atrial pressure             | Underestimation of true values in anesthetized patients |
|                            | Less affected by heart rate                   |                                                          | Large inter- and intraobserver variability in anesthetized patients |
| 3D-RV EF (%)               | Includes also RV outflow tract                | Depends on image quality                                 | Predictive value perioperatively not established |
|                            | Correlates well with eMRI                    | Requires offline analysis                                | Often used as reference technique in recent trials on perioperative |
|                            | Validated                                     |                                                          | Echocardiography                                 |
| 2D-RV FWS                  | Angle-independent                             | Vendor-dependent                                          | Heterogenous data on perioperative course        |
|                            | Established prognostic value, Validated       | Depends on image quality                                 | Predictive value perioperatively not established |
|                            | (e.g., out-of-plane motion)                  | Limited by two-dimensional approach                      | May distinguish perioperative changes of contraction quality |
| 3D-RV FWS                  | Independent of geometric assumptions          | Depends on image quality                                 | Normal TEE values not established                |
|                            | No out-of-plane motion of speckles           | Requires offline analysis                                | Limited data                                     |
| **Diastolic function**     |                                               |                                                          |                                                  |
| Et/At                      | Easy to obtain                                | Load-dependent                                           | Normal TEE values not established                |
|                            | Simple and fast                               | Heart rate–dependent                                     | Limited data                                     |
|                            | Validated                                     |                                                          |                                                  |
| e’ (TDI)                   | Easy to obtain                                | Load-dependent                                           | Normal TEE values not established                |
|                            | Simple and fast                               | Heart rate–dependent                                     | Limited data                                     |
|                            | Validated                                     |                                                          |                                                  |
| E/e’                       | Easy to obtain                                | Load-dependent                                           | Normal TEE values not established                |
|                            | Simple and fast                               | Heart rate–dependent                                     | Limited data                                     |
|                            | Validated                                     |                                                          |                                                  |

Adopted from Lang et al. [10], Badano et al. [54] and Rudski et al. [11]

RV, right ventricular; RVEDD, right ventricular end-diastolic diameter; TAPSE, tricuspid annular plane systolic excursion; RV S’, tricuspid annular systolic velocity; RV FAC, right ventricular fractional area change; RV MPI, right ventricular myocardial performance index; 3D-RV EF, three-dimensional right ventricular ejection fraction; 2D-RV FWS, two-dimensional derived right ventricular free wall strain; 3D-RV FWS, three-dimensional derived right ventricular free wall strain; Et, peak velocity of early tricuspid inflow; At, peak velocity of late tricuspid inflow; TDI, tissue Doppler imaging; TTE, transthoracic echocardiography; cMRI, cardiac magnet resonance tomography; CPB, cardiopulmonary bypass
and TEE measures of RV FAC are sparse. Skinner et al. assess the entire RV in the image plane, including the apex area in relation to diastolic RV area. It is of great importance to ed in a four-chamber view and describes the change of RV 

Assessed by TEE, underestimated RV $S'_r$ velocities measured by tissue Doppler imaging in alternative views, assessed by TEE, underestimated RV $S'_r$ in comparison to RV $S'_r$, assessed by TTE from the apical four-chamber view [27, 35].

A novel speckle-tracking-based method for measuring RV $S'_r$ in the mid-esophageal four-chamber view was described by Mauermann et al. [29], and showed promising results in 24 out of 25 evaluated patients.

**Right Ventricular Fractional Area Change (RV FAC)** RV FAC is a measure of global RV systolic function [10, 11]. It is obtained in a four-chamber view and describes the change of RV area in relation to diastolic RV area. It is of great importance to assess the entire RV in the image plane, including the apex during the complete contraction. RV FAC of < 0.35% suggests RV systolic dysfunction [10].

RV FAC correlates well with RV ejection fraction (RV EF) assessed by cMRI [36], and with echocardiographic measured three-dimensional RV EF [37]. Assessed either by TTE or by TEE, RV FAC is associated with postoperative morbidity and mortality [8, 38]. Data comparing TTE and TEE measures of RV FAC are sparse. Skinner et al. [39] showed that TTE and TEE measures of RV FAC did not differ significantly in spontaneously breathing patients. Roberts and colleagues found a fair agreement between TEE and TTE measurement of RV FAC in a heterogenous cardiac surgery population [40].

**Right Ventricular Myocardial Performance Index (RV MPI)** RV MPI is a non-geometric measure of global RV function, calculated by the summation of the isovolumetric contraction and relaxation times divided by the ejection time [41]. Evaluated from the same heartbeat, the isovolumic contraction time, the isovolumic relaxation time, and ejection time intervals should be measured either by pulsedwave (PW) Doppler or tissue Doppler (TDI) [10, 11]. In conditions with elevated right atrial pressure, which shortens isovolumetric relaxation time, RV MPI may be incorrectly reduced. RV MPI >0.43 assessed by PW-Doppler or >0.54 evaluated by TDI implies RV dysfunction [10].

RV MPI measured by TTE showed to be a predictor of adverse events, mainly in patients with pulmonary hypertension [41, 42]. Preoperative RV MPI evaluated by TEE was independently associated with mortality and morbidity after left-sided heart valve surgery [38].

Michaux et al. [43] compared RV MPI measurements in awake spontaneously breathing patients scheduled for coronary artery bypass surgery, preoperatively by TTE and intraoperatively after induction of anesthesia by TEE. RV MPI values were significantly lower in anesthetized patients under positive pressure ventilation. Moreover, variability was four-fold higher in TEE measures. Therefore, Michaux and colleagues questioned RV MPI as an adequate parameter for RV function assessment in anesthetized patients under positive pressure ventilation [43]. Roberts at al. found only slight agreement for RV MPI between TEE and TTE evaluation in anesthetized patients [40].

**Novel Echocardiographic Parameters**

**Three-dimensional Right Ventricular Ejection Fraction (3D-RV EF)** According to the current ASE/EACVI guidelines, evaluation of three-dimensional RV volumetry and ejection fraction (3D-RV EF) should complement two-dimensional measures of RV function, when feasible [10]. Three-dimensional echocardiography allows the evaluation of RV shape, size, and function without the limitations of two-dimensional assessment. It is independent of geometric assumptions; includes the evaluation of the inflow, outflow, and apical segments; and correlates well with cMRI [10]. 3D-RV EF depends on an adequate image quality and requires an offline analysis as software is often not included on the echo machines [10]. TTE [44] and TEE [22] guidelines for performing three-dimensional echocardiography of the right heart were published. TEE may provide high-resolution and superior quality images of the right heart compared to TTE [22]. 3D-RV EF correlates well with cardiac magnetic resonance–derived RV EF; as the gold standard for evaluation of RV function [45], and is feasible intraoperatively [46, 47]. However, the predictive value in cardiac and non-cardiac surgery patients was not tested in adequately powered prospective studies [12, 20, 48]. Nonetheless, 3D-RV EF assessed by TEE is increasingly used as the reference method in the intraoperative setting [20, 49, 50]. The current ASE/EACVI guidelines state that 3D-RV EF < 45%, assessed by TTE in awake spontaneous breathing patients, implies dysfunction [10].

**RV Strain Analysis** Myocardial strain analysis with speckle-tracking echocardiography (STE) is an upcoming technology to assess peroperative right ventricular function [51•]. Strain is a dimensionless parameter describing myocardial deformation, the fractional change in the length of myocardial segments. Deformation may appear in longitudinal, circumferential, or radial dimension. Strain can have positive or negative values, which reflect lengthening or shortening, respectively. It has the advantage to be less dependent on loading conditions than other echocardiographic parameters of RV function assessment, has a small interobserver variability, is relatively...
angle-independent, and does not rely on geometric assumptions [52]. It is, however, influenced by image quality, artefacts as reverberation or attenuation, and is vendor-dependent [52]. In the context of the RV, predominantly right ventricular global longitudinal strain (RV GLS), which incorporates RV free wall segments and the interventricular septum segments, or right ventricular longitudinal free wall strain (RV FWS), which exclusively includes RV free wall segments, is used in clinical practice [52].

Two-dimensional RV strain (2D-RV strain) correlates well with cMRI-derived RV EF and seems to have higher diagnostic accuracy for detection of RV dysfunction compared to conventional parameters [36, 53]. To standardize deformation imaging, the ASE and EACVI published a consensus document, which includes recommendations for two-dimensional RV strain assessment [54]. The current ASE/EACVI guideline on chamber quantification states that 2D-RV strain parameters are useful for estimating RV global and regional systolic function and have an established prognostic value in various cardiac conditions [10]. 2D-RV free wall strain greater than -20 is expected to be abnormal in awake, spontaneous breathing patients evaluated by TEE [10].

Perioperative TTE–derived 2D-RV FWS is reduced after cardiac surgery with [24, 55] and without extracorporeal circulation [56]; however, it remains unchanged after transcatheter aortic valve repair (TAVR) [24]. It predicts RV failure after left ventricular assist device (LVAD) surgery [57, 58] and correlates with postoperative mortality in cardiac surgery [8, 59], as well as in patients undergoing TAVR [60].

Less is known for intraoperative 2D-RV strain assessed by TEE since most of the knowledge on RV strain analysis has been obtained by TTE in awake patients. Intraoperative 2D-RV strain analysis is feasible [61] and impaired 2D-RV GLS seems to be associated with postoperative atrial fibrillation [62] and prolonged postoperative vasoactive support [63]. Surprisingly, intraoperative 2D-RV strain assessed by TEE poorly predicts RV failure after LVAD implantation [64, 65].

There is inconsistent data, however, on the perioperative course of 2D-RV strain in cardiac surgery [49, 50, 66, 67]. This variability might be explained by differences in evaluated surgical procedures, severity of the conditions, time of echocardiographic assessment, and the use of vasoactive treatment during echocardiography. Various applied techniques for myocardial protection during cardiopulmonary bypass and different surgical practice itself may additionally influence postoperative RV function, and therefore strain, respectively. Furthermore, assessment of the complex RV with two-dimensional strain analysis might be biased, mainly by out-of-plane movement of the analyzed speckles [68] and foreshortened views [69]. For all mentioned above, there are no generally accepted normal TEE values for intraoperative 2D-RV strain. More trials, standardization, and probably alternative techniques, overcoming the limitations of two-dimensional approach, seem to be necessary to draw further conclusions.

Three-dimensionally derived RV FWS (3D-RV FWS) overcomes these limitations by 3D full-volume assessment that incorporates the entire RV and is independent of geometric assumptions [48, 52]. Intraoperative 3D-RV FWS is feasible and promising; however, existing data is sparse [51••].

In a retrospective case series, Keller et al. [70] analyzed one-time intraoperative 3D-RV FWS, compared this method to other techniques of intraoperative RV FWS assessment, and found good agreement between analyzed methods. In another retrospective trial, Keller and colleagues showed differences in perioperative changes of 3D-RV FWS between mitral valve surgery, off-pump CABG (OPCAB), and in percutaneous mitral valve repair (PMVR) [71•]. Regarding our own published data [72], 3D-RV FWS seems not to differ significantly in awake, spontaneously breathing patients and in patients under general anesthesia and positive pressure ventilation with stable hemodynamics. It remained unchanged after sternotomy but deteriorated after on-pump coronary artery bypass surgery in our group of patients. More data is needed to draw reliable conclusions.

### RV Diastolic Function

Various acute and chronic conditions are associated with RV diastolic dysfunction (RVDD), including both pressure and volume overload conditions in LV dysfunction, heart valve disease, pulmonary embolism, lung disease, ischemic heart disease, cardiomyopathies, and different systemic diseases affecting the heart and the lung [11]. Assessment of RVDD is of clinical value as it serves as an early marker of RV dysfunction which commonly develops before obvious systolic RV dysfunction and before RV dilatation appears [11]. Presence of RVDD is associated with less exercise capacity and is an independent predictor of mortality in patients with heart failure and pulmonary hypertension [11].

RVDD seems to be of prognostic relevance also in the perioperative setting [58, 73, 74].

For evaluation of RVDD, current ASE/EACVI guidelines recommend assessment of tricuspid valve inflow (Et, At) and lateral tricuspid annular tissue Doppler velocity (et’). Traditionally perioperative RVDD was recognized in patients with severe LV dysfunction [58, 73]. Recently, Sumin et al. [74•] found up to 46% of patients scheduled for non-emergency CABG surgery with preserved LV and RV systolic function to have RVDD using the recommended approach [11]. Analyzing their data, the decreased Et/At ratio was the best echocardiographic marker predicting postoperative heart failure development after CABG surgery in their patient population.
The best monitoring tool for perioperative RVDD assessment needs to be established [75]. Recently, strain-based parameters have been described for assessment of left ventricular diastolic dysfunction [76], but the authors of this review are unaware of studies on RVDD based on strain analysis. Unquestionably, more data is needed to draw conclusions on RVDD in the perioperative setting.

TTE Versus TEE Assessment

Both, TTE and TEE, are crucial parts of perioperative RV function assessment [1, 10]. TEE offers superior image quality and is the imaging mode of choice in the intraoperative setting complementing invasive hemodynamic measures. But it may not be adequate in awake patients in the direct postoperative period. In contrast, validated data on reference values largely relies on guidelines derived from TTE studies on the awake patient [10, 11], but image quality after cardiac surgery can be challenging. Image plane and angles of assessment have an effect on the values of RV measures [10, 11], and even slight modifications showed statistically significant differences in measured values, particularly in the context of RV function assessment [77].

For TEE evaluation, the best perioperative measure is yet to be established, since the parameters of RV function assessment are not interchangeable between TTE and TEE [12]. Particularly, the regional longitudinal parameters TAPSE and RV S′ seem to be underestimated by TEE compared to those by TTE evaluation [27, 40]. But also, RV MPI as global measure of RV function showed at most moderate correlation [40, 43] and a high inter- and intraobserver variability [43]. Therefore, echocardiographers should be cautious in extrapolating these measures validated by TTE studies to their TEE examinations. Global measures of RV function as RV FAC [39, 40], 3D-RV EF [46], 2D-RV GLS [61, 78], and 3D-RV FWS [72] assessed by TEE seem to correlate better with TTE assessment and may provide better agreement with validated reference values.

Perioperative Course

Cardiac surgery causes functional and geometric changes of the RV that are not entirely understood and often depend on the performed procedures. Existing data suggest postoperative reduced longitudinal RV function while global RV function is preserved [32, 33]. Moreover, data from 2D strain-based analyses suggests that longitudinal RV function decreases, whereas transverse/circumferential function might improve [49, 55].

Moreover, administration of anesthetics and the change from spontaneous respiration to intermittent positive pressure ventilation may affect “normal” echocardiographic values [79, 80]. Therefore, normal values assessed by TTE in spontaneous breathing patients are not interchangeable with values assessed by TEE in anesthetized and ventilated patients. Further research is required addressing this issue.

Comparison to Other Techniques of RV Function Assessment

Cardiac magnetic resonance tomography (cMRT) remains the gold standard of cardiac imaging. But it is not practical in the perioperative setting with rapid changes of hemodynamic conditions.

The use of pulmonary artery catheter (PAC) has been the gold standard of cardiac output measurement for the last decades. Although its use in critical ill patients has been questioned heavily in the last years, PAC remains an effective means of monitoring RV function in the perioperative setting [81]. It is still a frequently used monitoring tool in cardiac surgery [82]. Particularly in complex and high-risk cases (e.g., LVAD implantation, heart transplantation, patient with severely depressed LV or RV function), PAC is of great value in perioperative decision-making [83]. But values of cardiac output measurement seem not to be interchangeable between PAC and echocardiography, even when 3D echocardiography is used [84, 85]. However, there are also reports describing a good correlation between both methods [86]. PAC complements information on RV function by providing pulmonary artery pressure monitoring and oxygen saturation [87, 88]. This is particularly important in difficult and complex situations and procedures [89, 90].

Future Directions

Global echocardiographic parameters of RV function assessment [40, 46] and strain-based parameters [61, 78] appear to have better agreement between TTE and TEE, and seem to describe RV function more accurately in the perioperative interval [50, 59]. Future studies should focus on exploring these parameters and their influence on patient outcome. Two-dimensional RV strain analysis is a promising technique needing standardization and validation in the context of cardiac and non-cardiac surgery [91, 92]. Having the opportunity to distinguish longitudinal, radial, and circumferential contraction [49, 55] RV strain analysis allow to differentiate perioperative changes of RV function in different procedures. Although in its infancy, perioperative three-dimensional RV strain analysis offers many features to overcome the problems of two-dimensional strain assessment and may help in decision-making [71, 72].

In high-risk patients and complex surgical procedures (e.g., LVAD implantation, heart transplantation, LCOS), combination of echocardiography and PAC on detection of RV failure should be explored [82].

Identifying RVDD seems to be of value in the perioperative setting. However, more data, either assessed by
echocardiography, by PAC, or even both techniques, is needed to draw further conclusions [75, 88]. The number of parameters or even technologies for RV function assessment has increased significantly, and evaluation has become more complex and time-consuming. In the context of a dynamic intraoperative setting with several demanding tasks, artificial intelligence might help the anesthesiologist in decision-making in time-critical situations [93, 94].

Conclusion

Both TTE and TEE are essential for perioperative assessment of RV function. For a complete evaluation of the complex structured RV, various parameters and views are required. RV contraction seems to change in the perioperative course, particularly in cardiac surgery. Novel echocardiographic techniques have found a reduced motion of longitudinal fibers and an increased deformation of transversal fibers after cardiac surgery. Myocardial strain analysis and three-dimensional echocardiography may provide further insight into these alterations of systolic and diastolic RV function in the perioperative period.

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